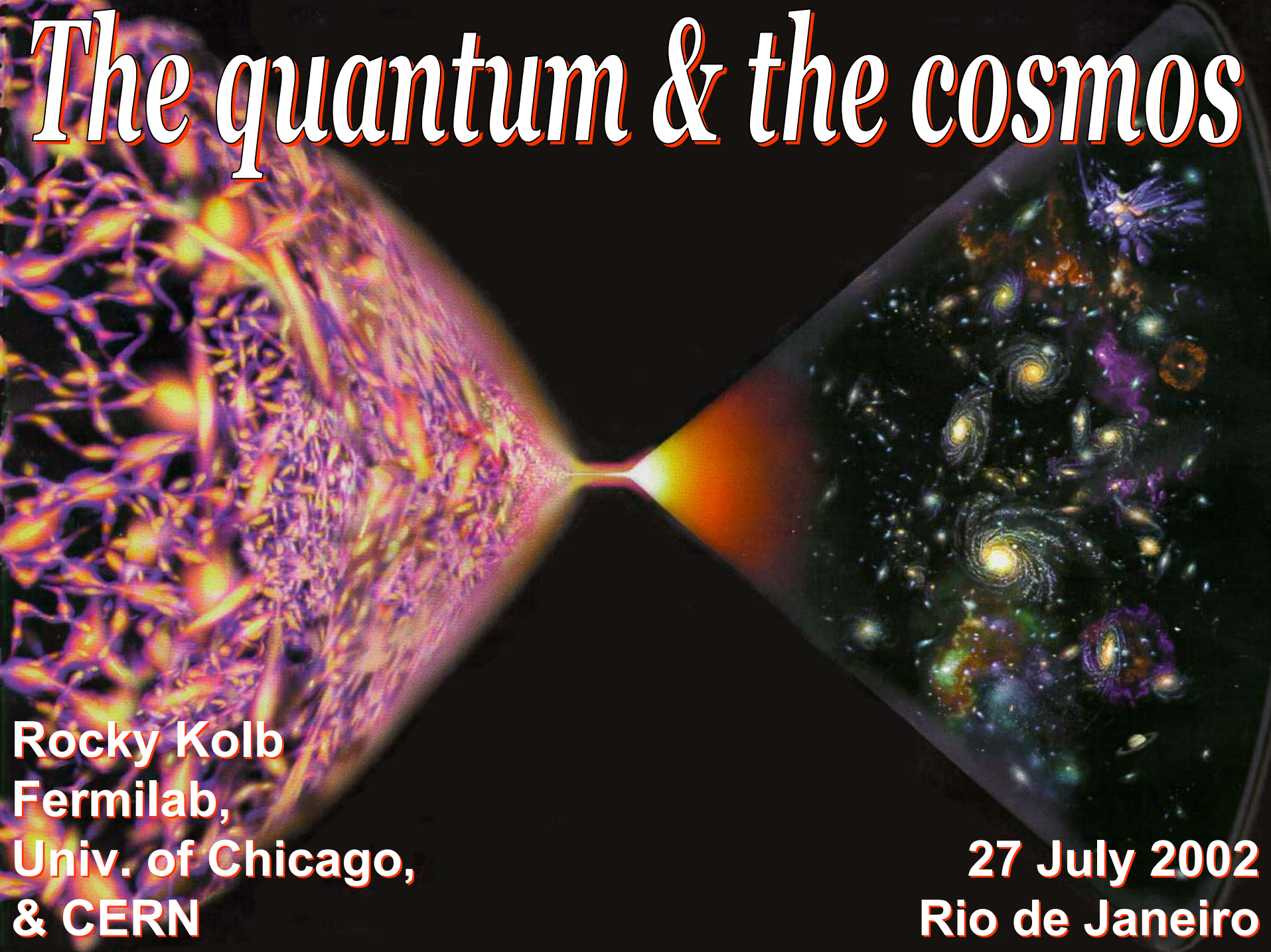
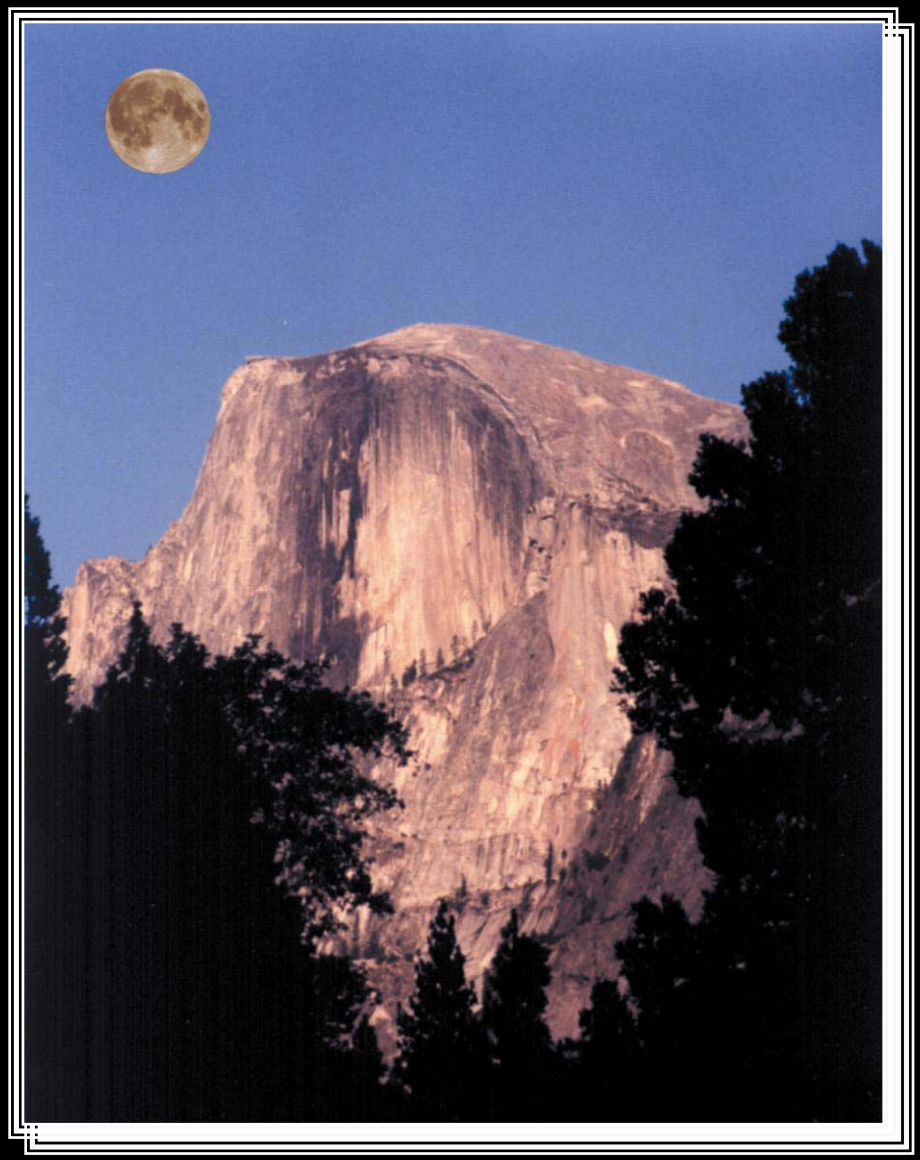
The quantum & the cosmos



Rocky Kolb
Fermilab,
Univ. of Chicago,
& CERN

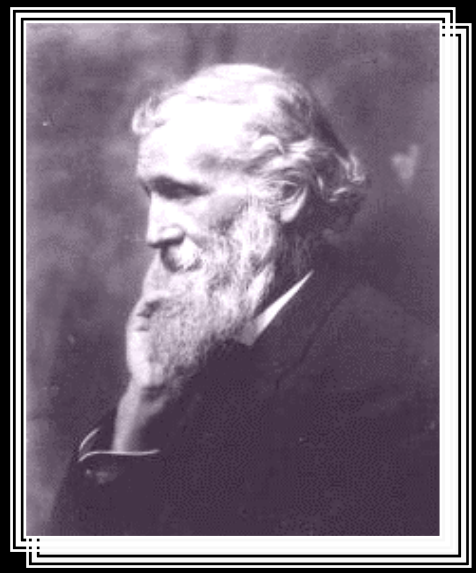
27 July 2002
Rio de Janeiro


via
della Fisica
viale
dell'Astronomia



When one tugs at a single thing in nature, he finds it hitched to the rest of the universe.

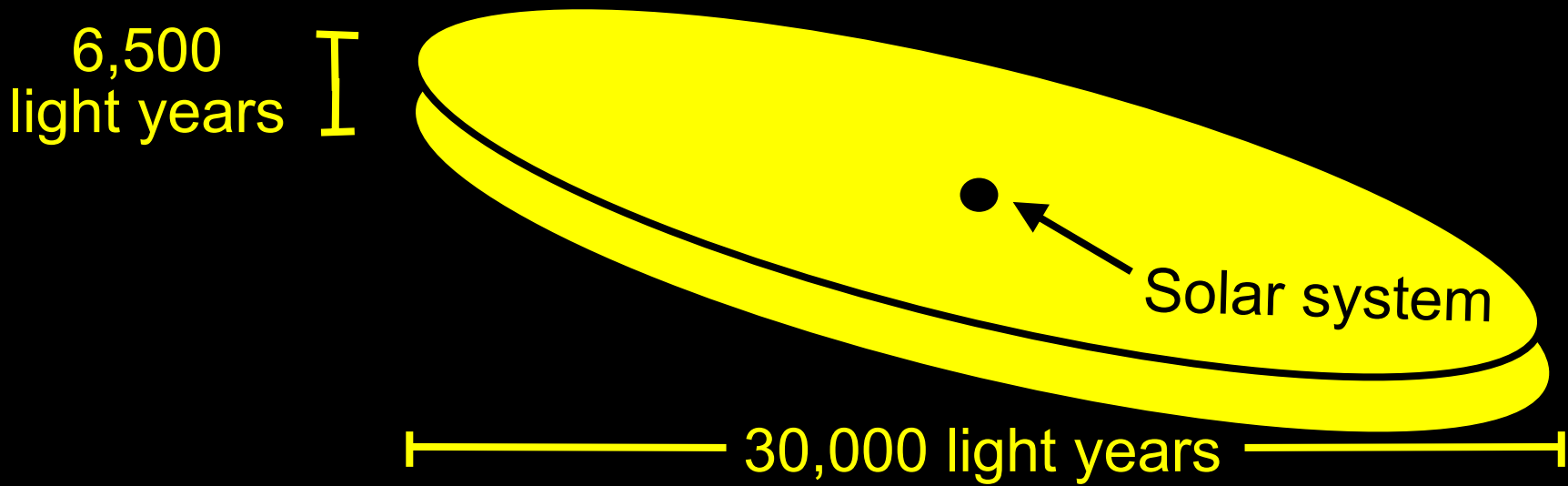
– John Muir



A view of the universe, circa 1902

Kapteyn Universe

1) Arrangement:



2) Composition: Starz' in the 'hood

3) Origin: ?

Space, time, and motion in the universe


ANDROMEDA
GALAXY

Space, time, and motion in the universe

The Milky Way

30,000 light years - 720,000 kph

The Milky Way

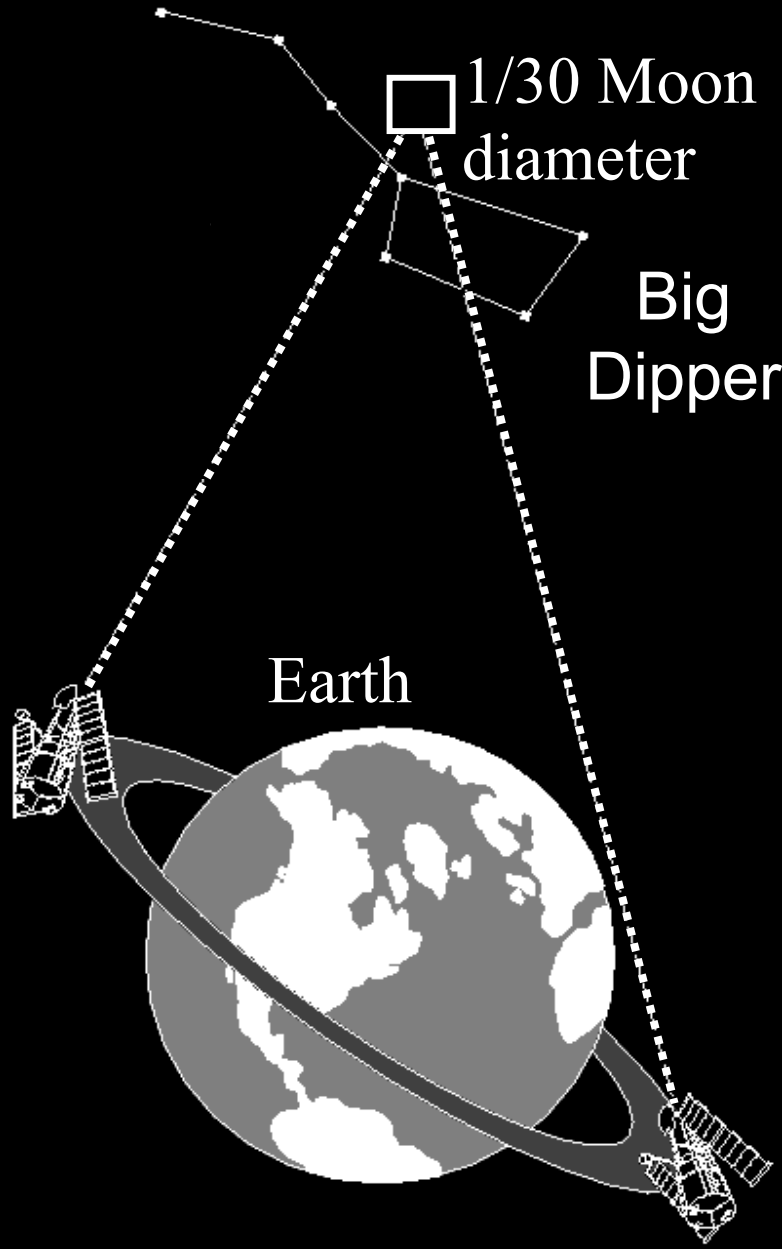
15 billion years

Andromeda

2 million light years-140,000 kph

A view of the universe, circa 2002 A.D.

Hubble Deep Field

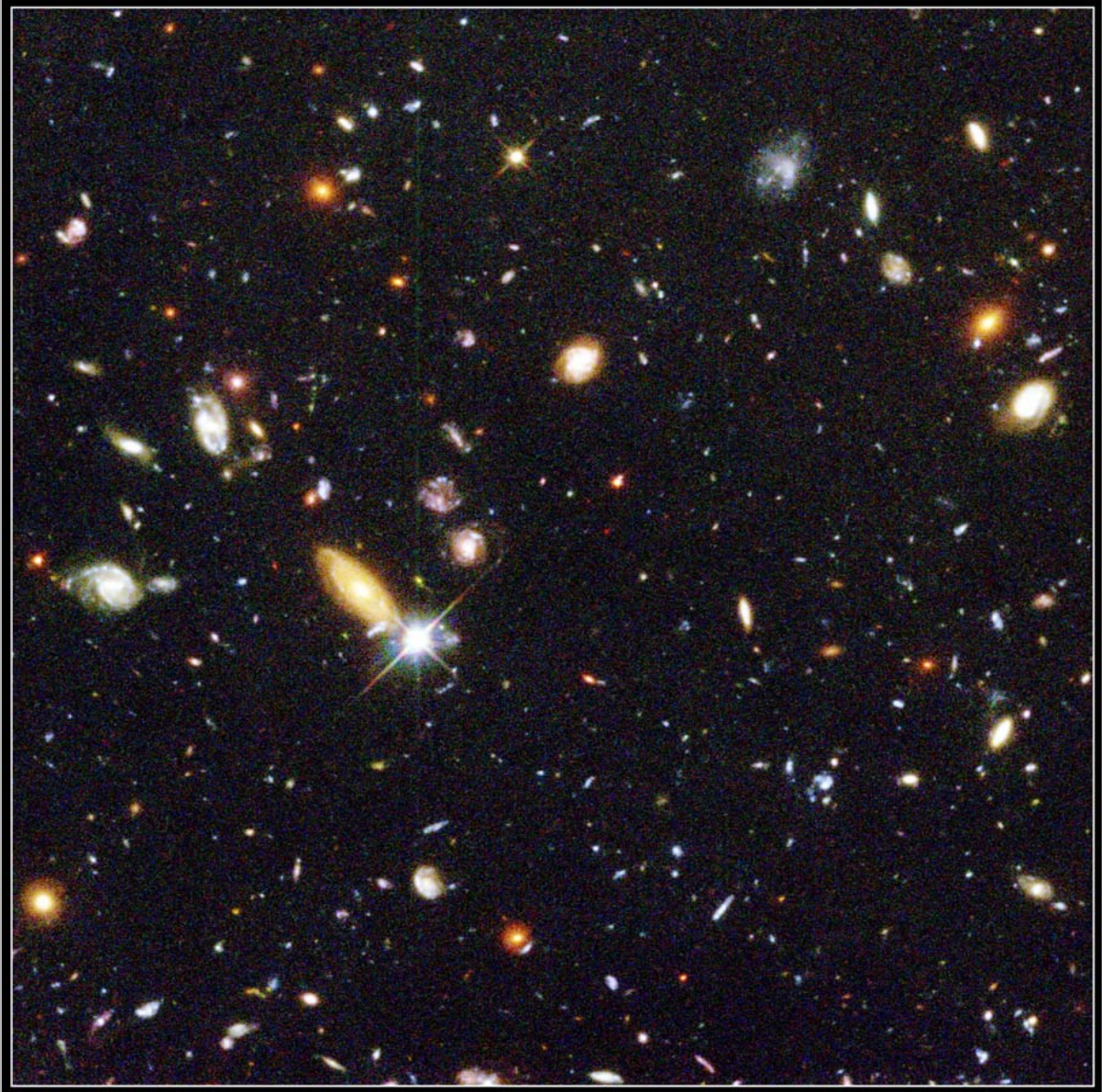


Hubble Deep Field

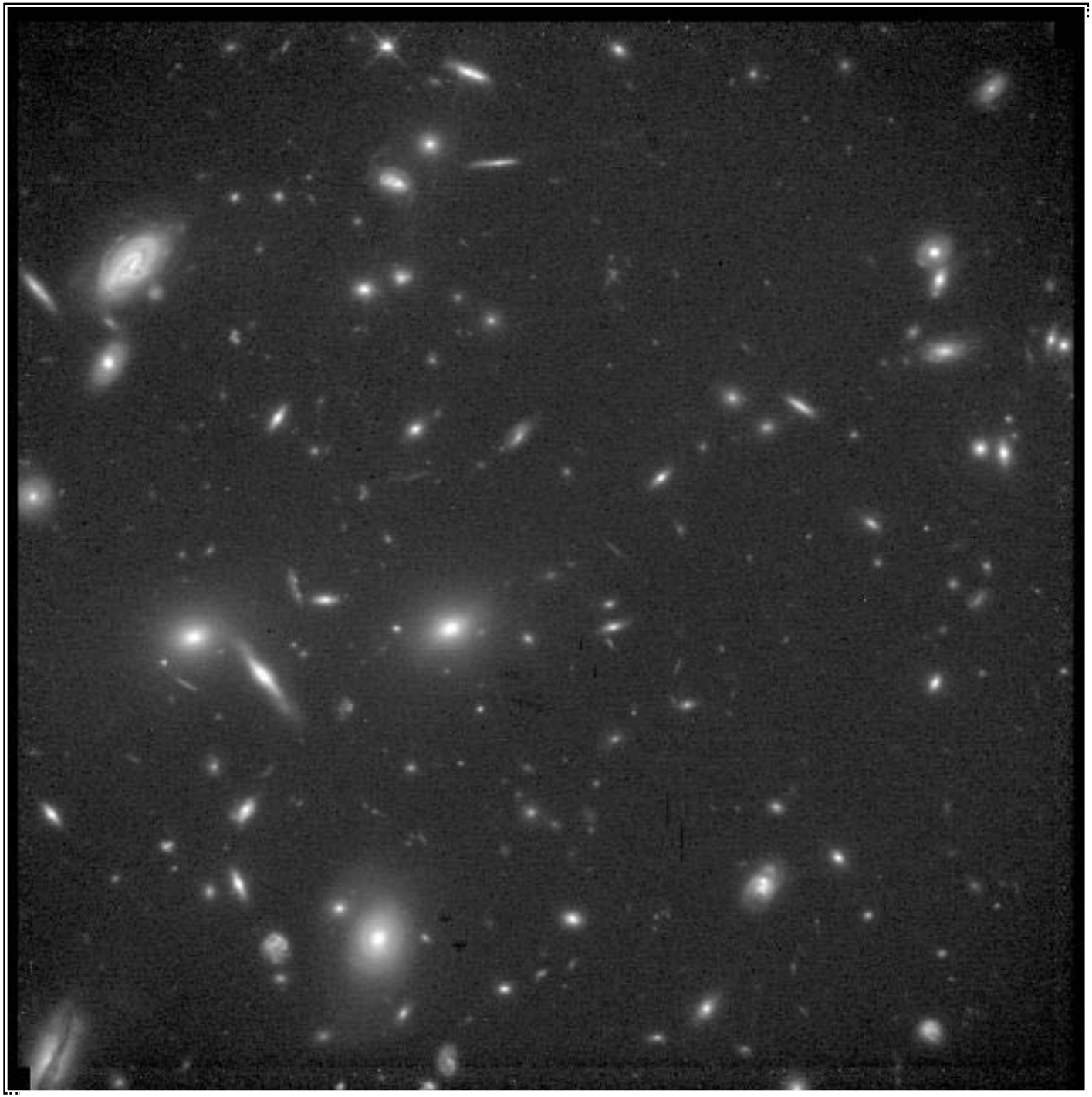
UNIVERSE OF GALAXIES

3000 here →

50 billion over entire sky



Cluster of Galaxies



Space, time, and motion in the universe

The Milky Way

30,000 light years - 720,000 kph

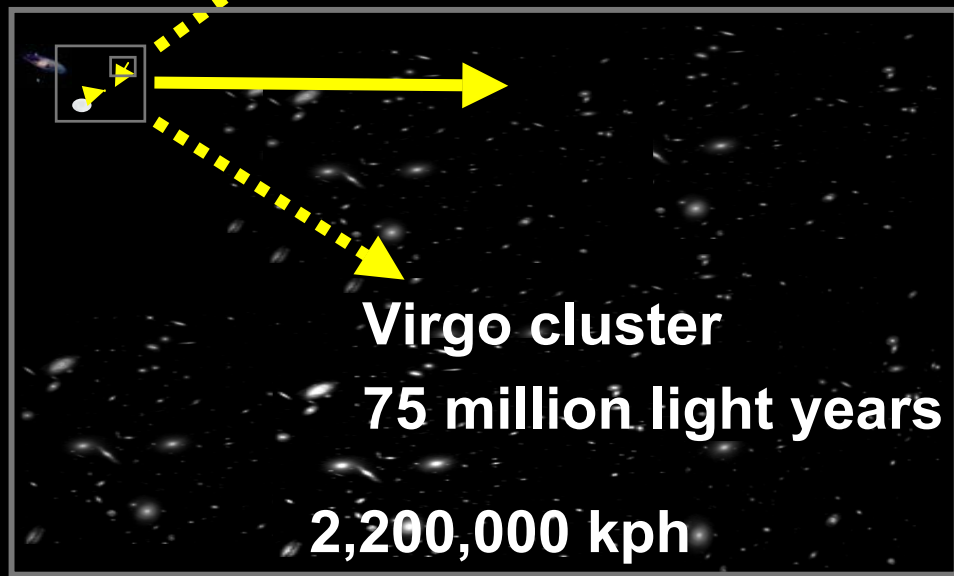
The Milky Way

Andromeda

2 million light years-140,000 kph

Hydra Supercluster

750 million light years

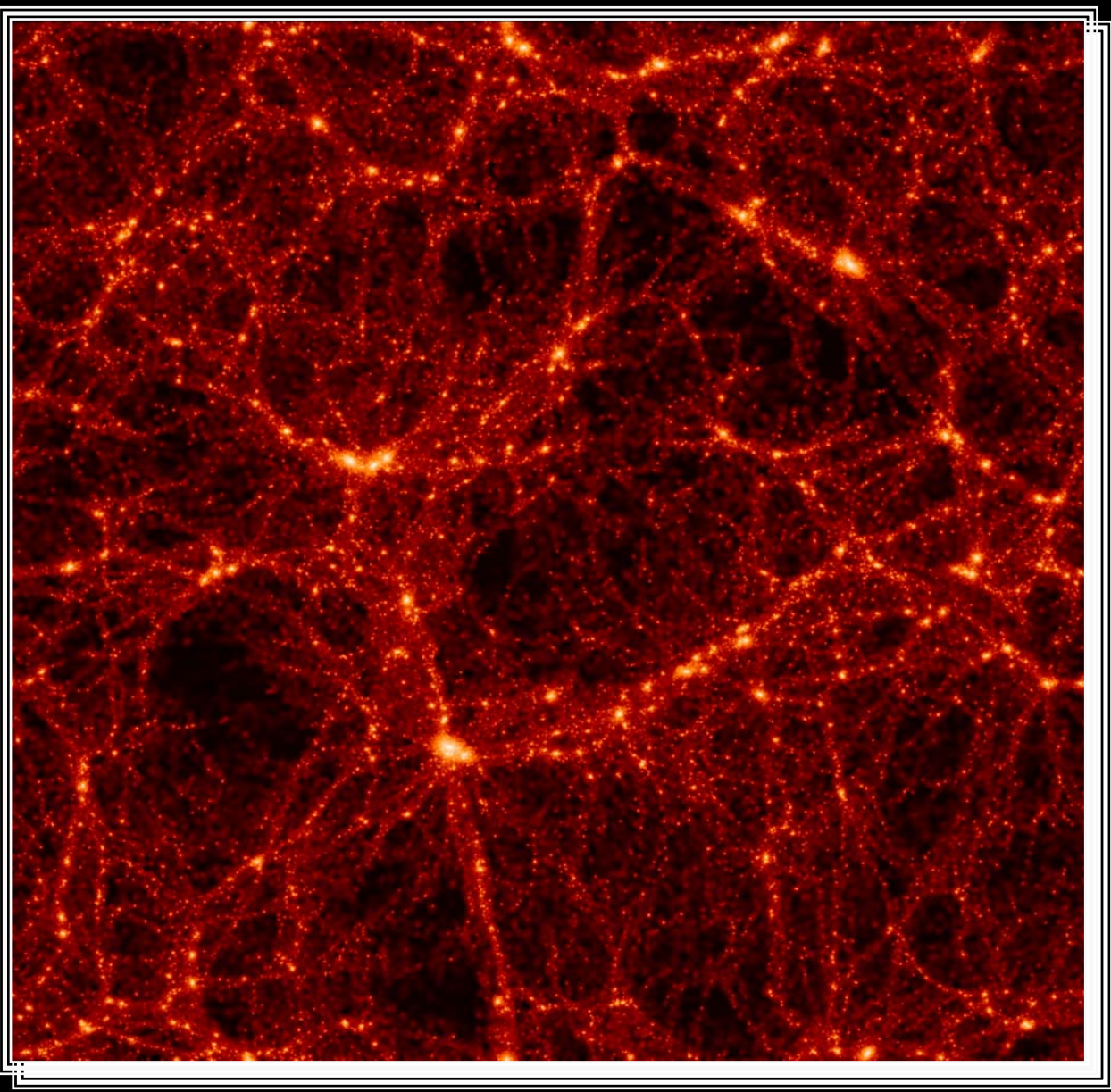


Virgo cluster

75 million light years

2,200,000 kph

The Cosmic Web



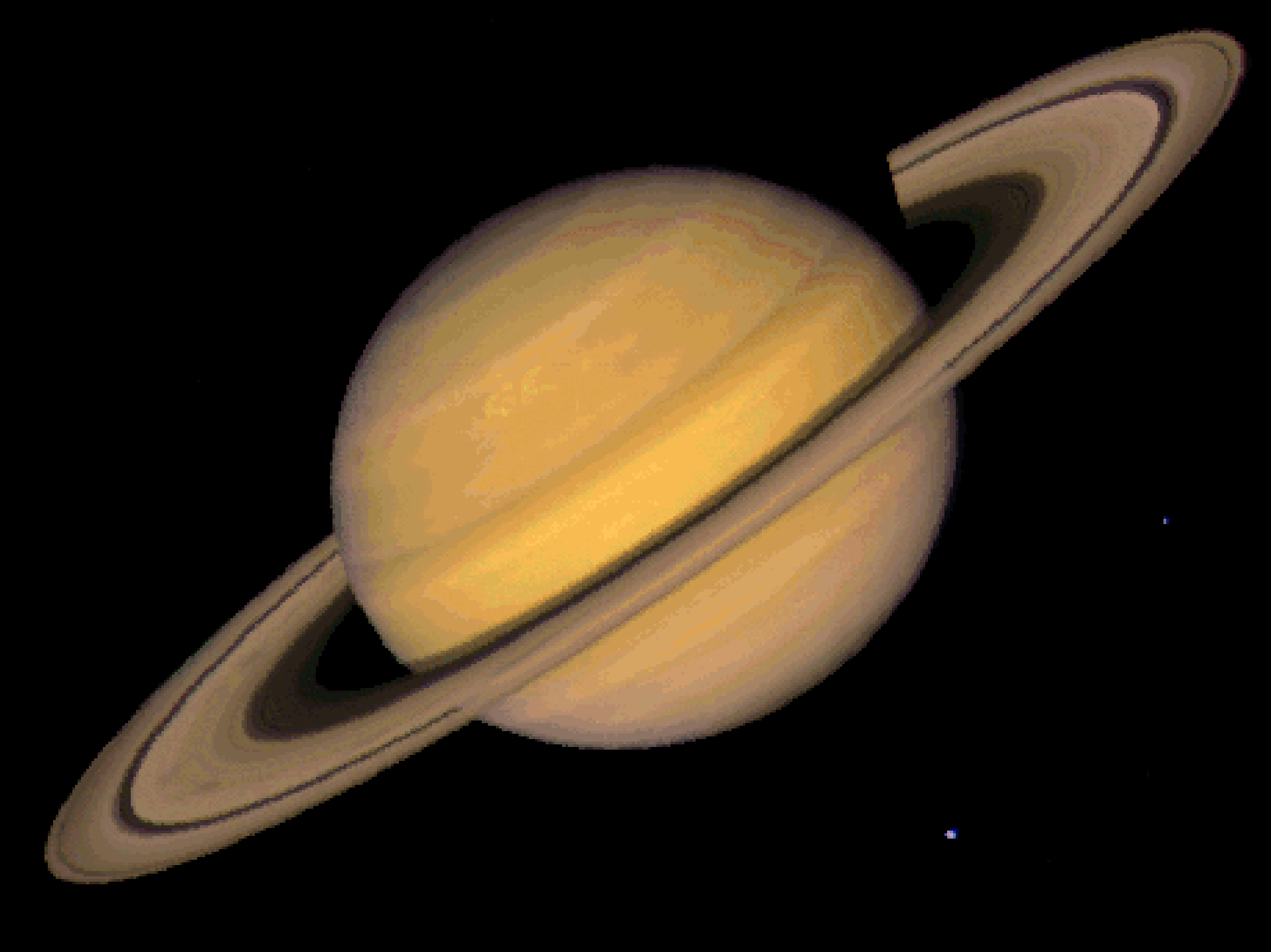
The VIRGO Project

What is the universe made of?

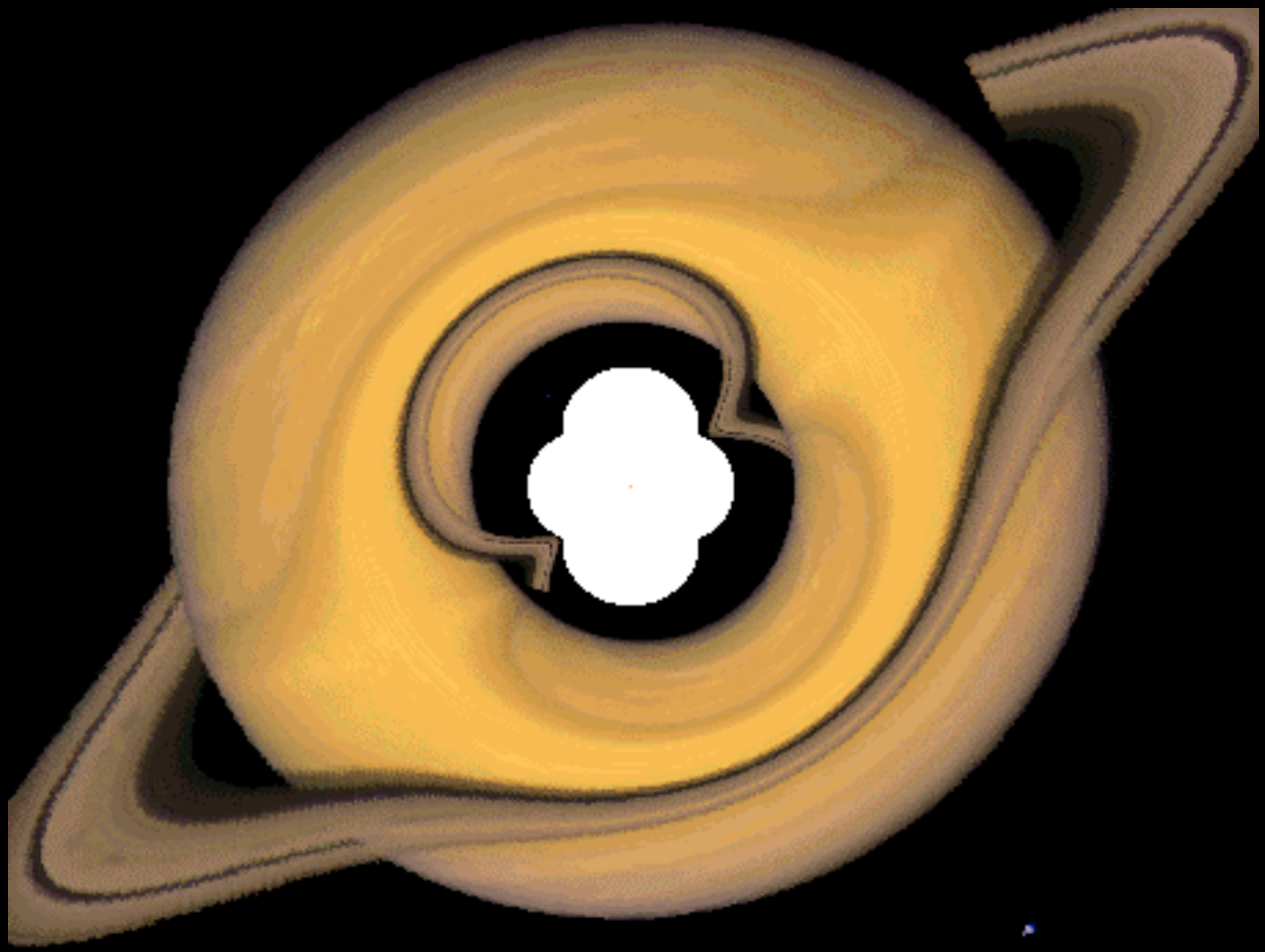
Galaxies: the visible universe

More than meets the eye!

NGC253 in Sculptor

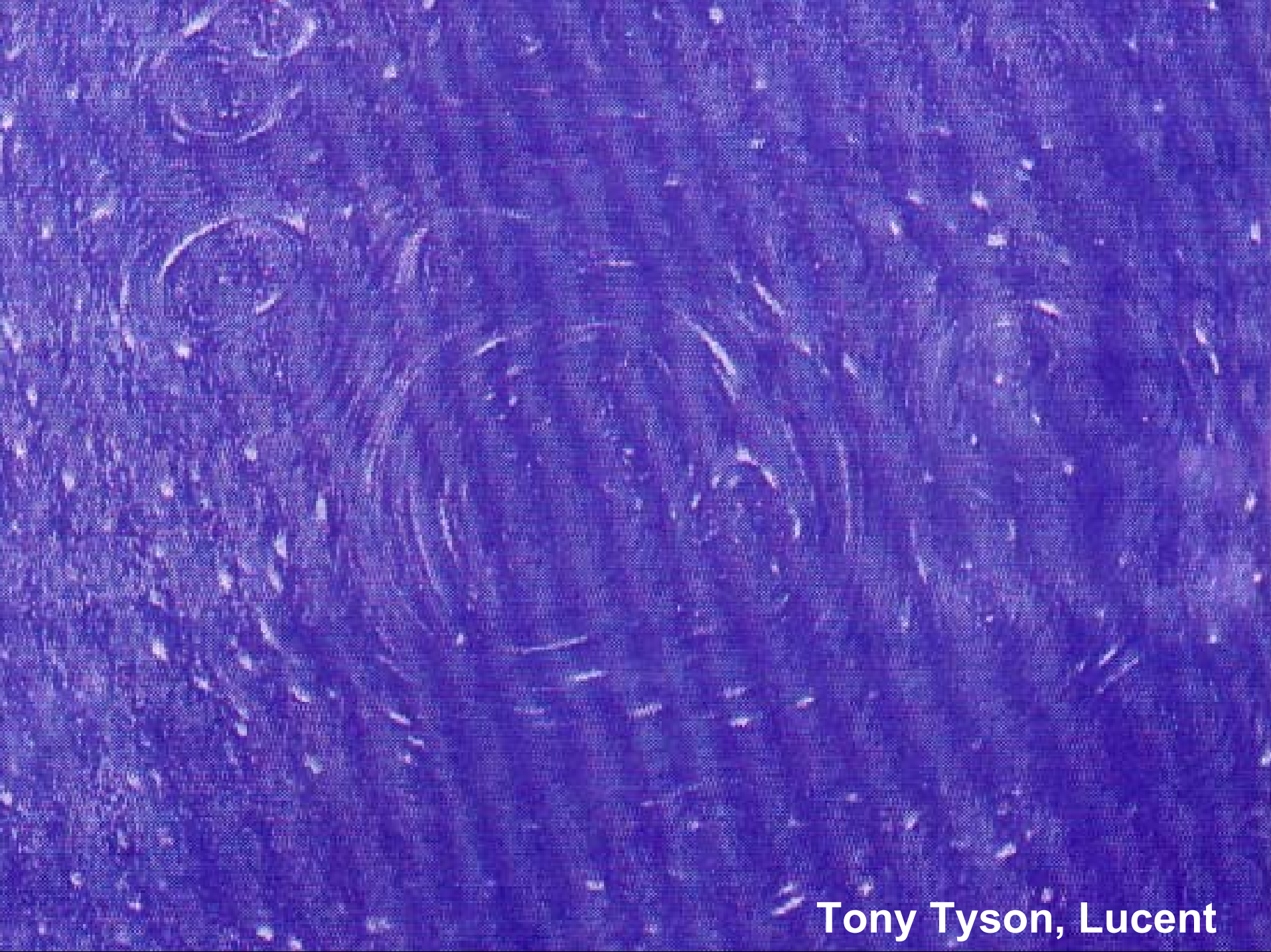


More than meets the eye!

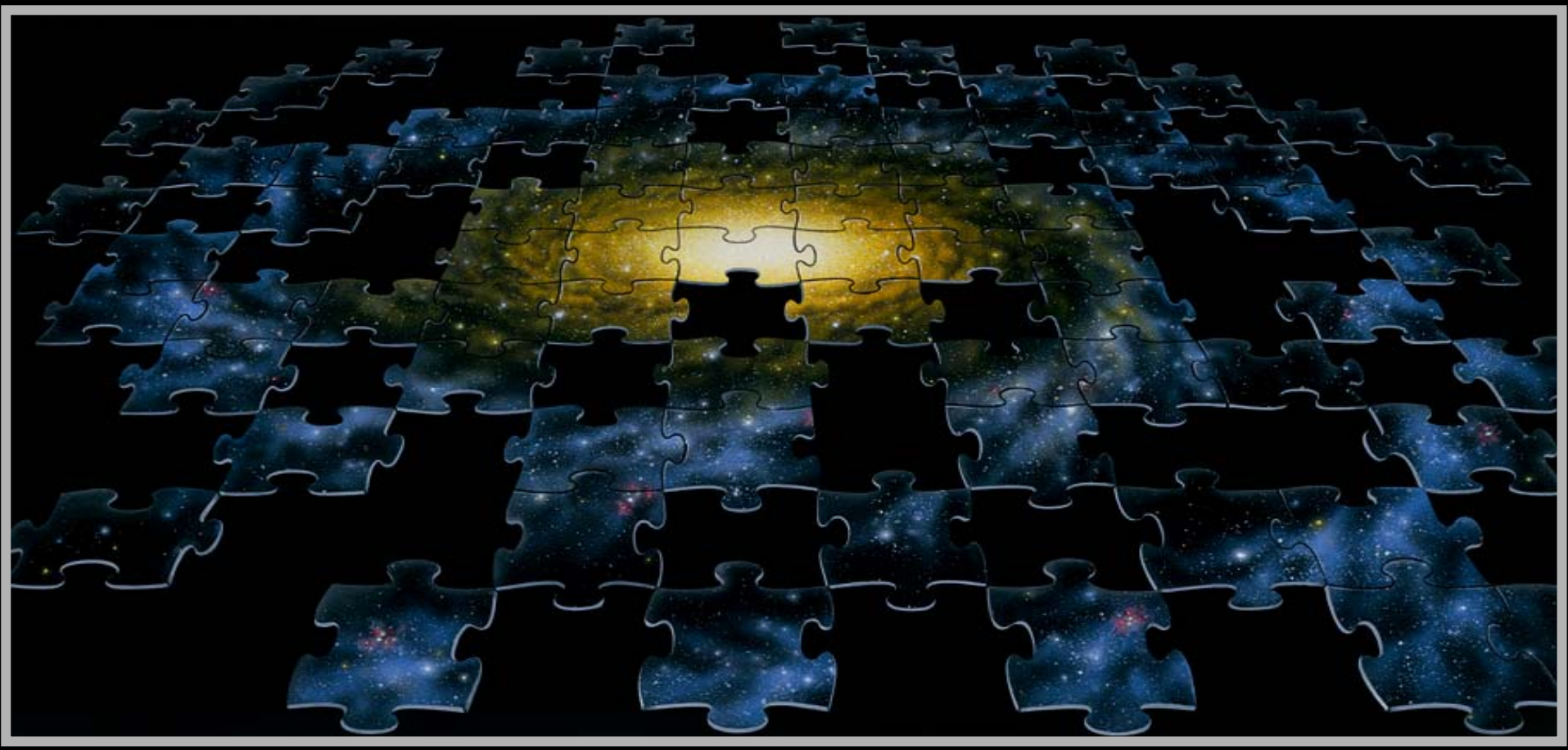


More than meets the eye!

Gravitational lens Galaxy cluster 0024+1654 (Hubble Space Telescope)


Tony Tyson, Lucent

What is the universe made of?



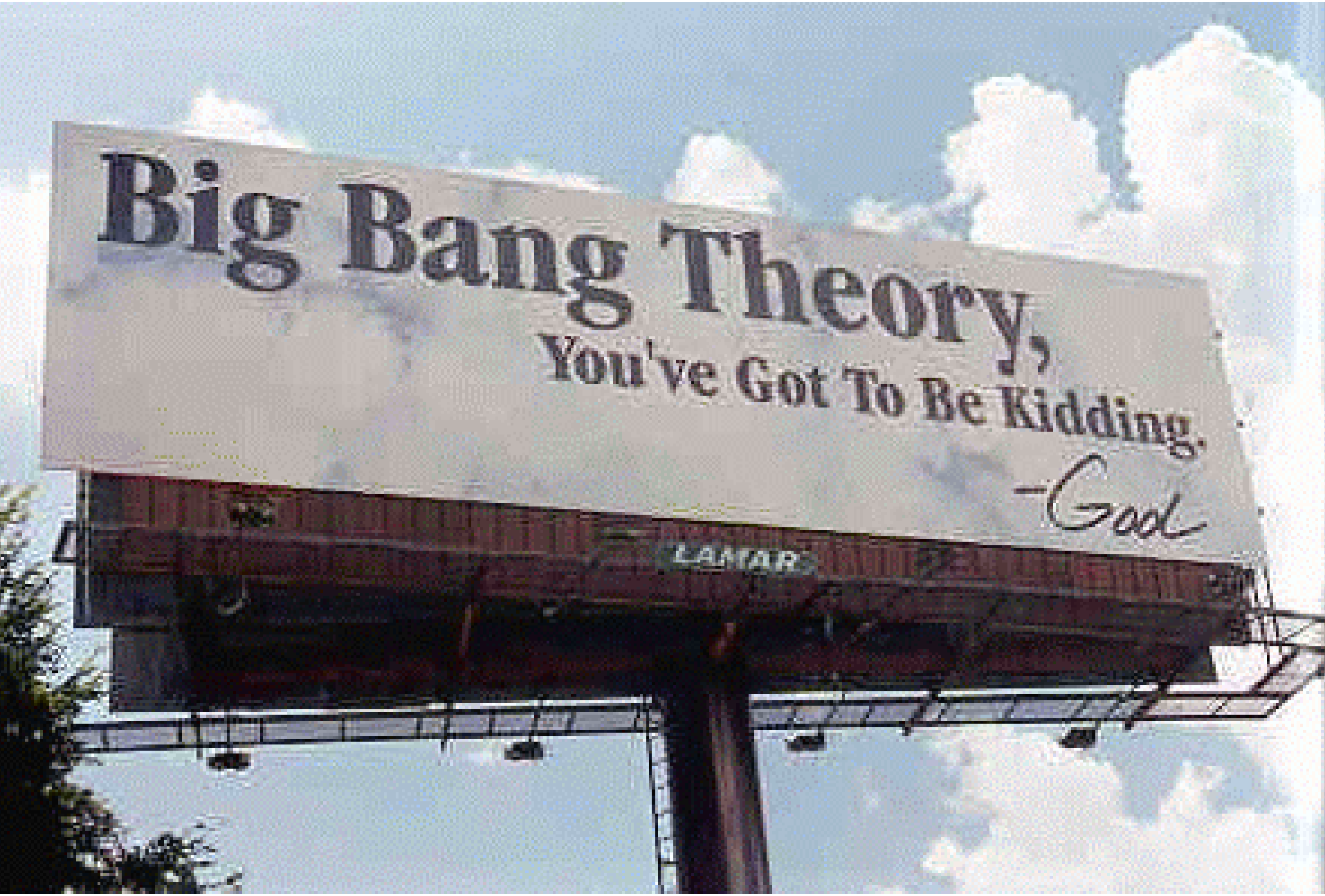
Dark Matter: the invisible universe

(300 times more dark than visible matter)

Most of the universe is dark !

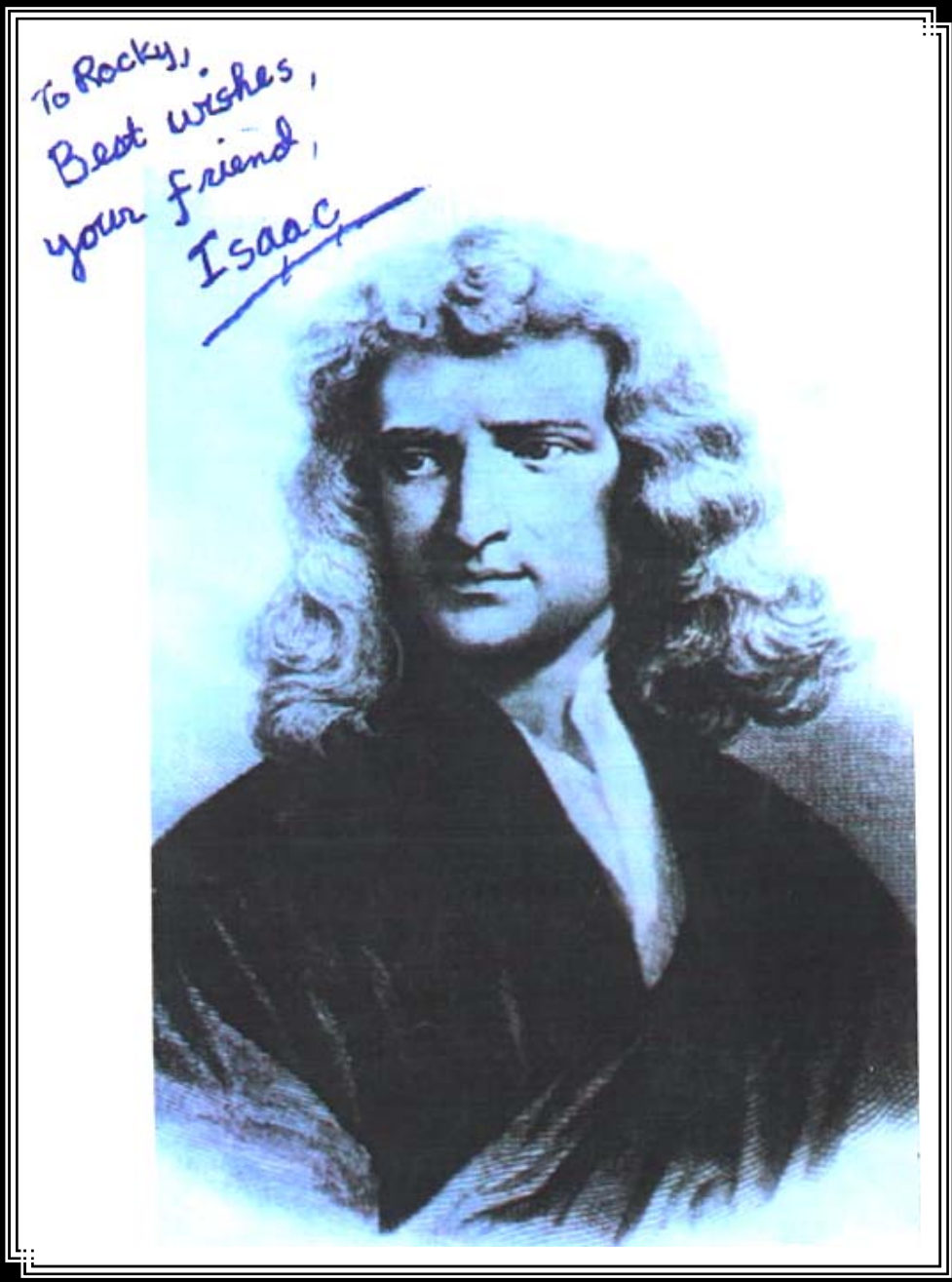
- Modify Newton's laws
- Rocky planets
- Mass disadvantaged stars

  brown red white
- Black holes
- Something cooked in the primordial soup of the big bang


Big Bang Theory,
You've Got To Be Kidding.
-God
LAMAR

Absolute space,
in its own nature,
without relation
to anything external,
remains always similar
and immovable.

Isaac Newton
1686
Principia



Space and time
are related.

Albert Einstein
1905

Space is dynamical
(curved, warped, bent,
etc.).

Albert Einstein
1915

Space expands.

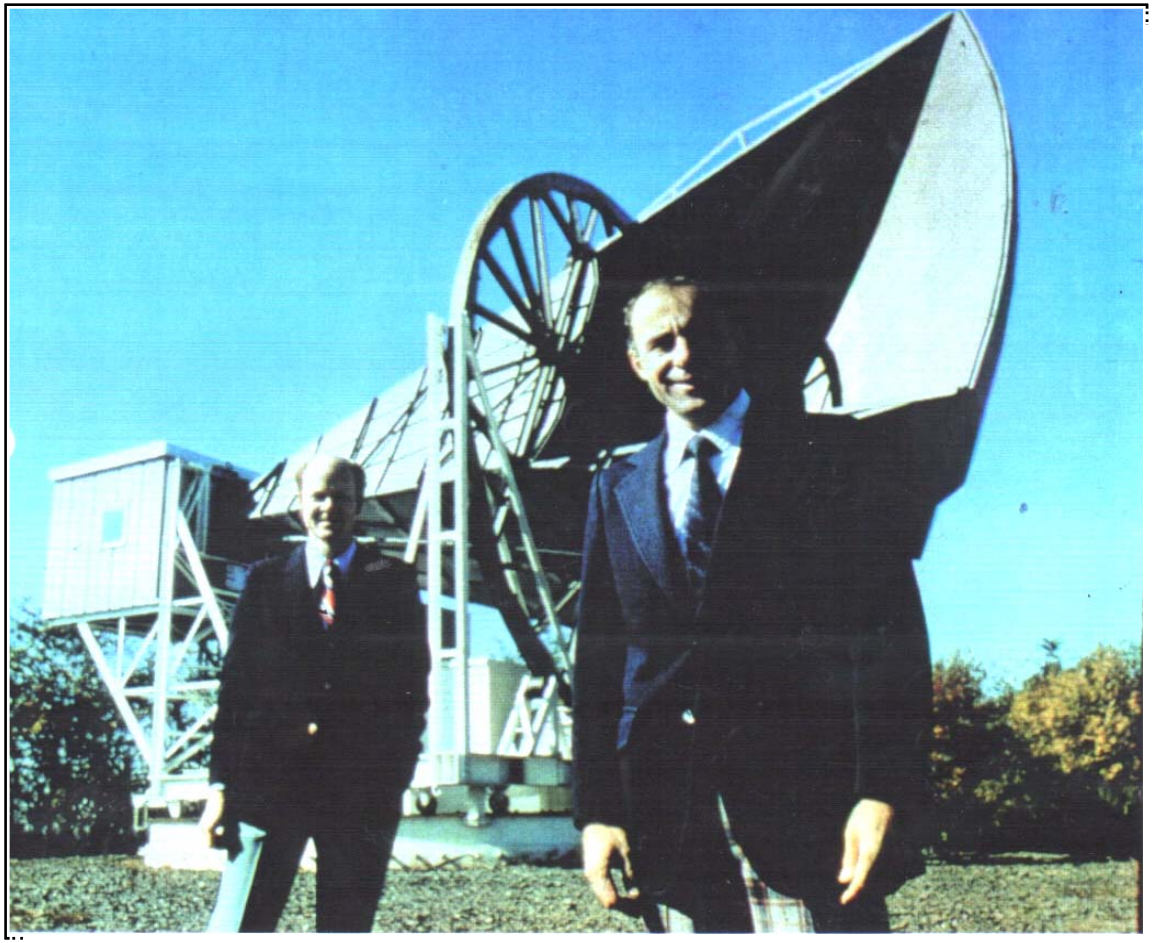
Edwin Hubble
1929

The University of Chicago

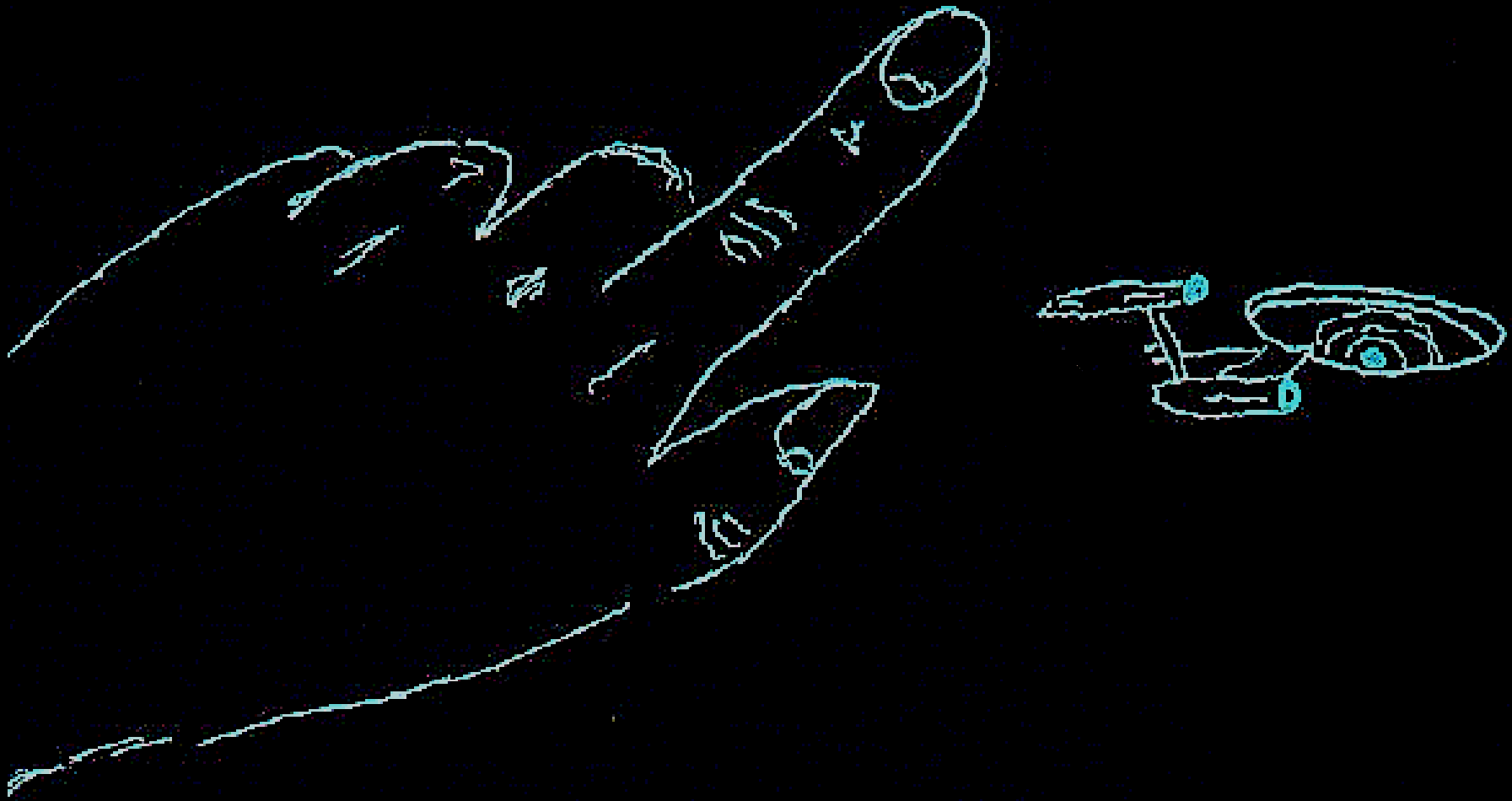
1909 National Champions

The universe
is radiant.

Arno Penzias
Robert Wilson
1965



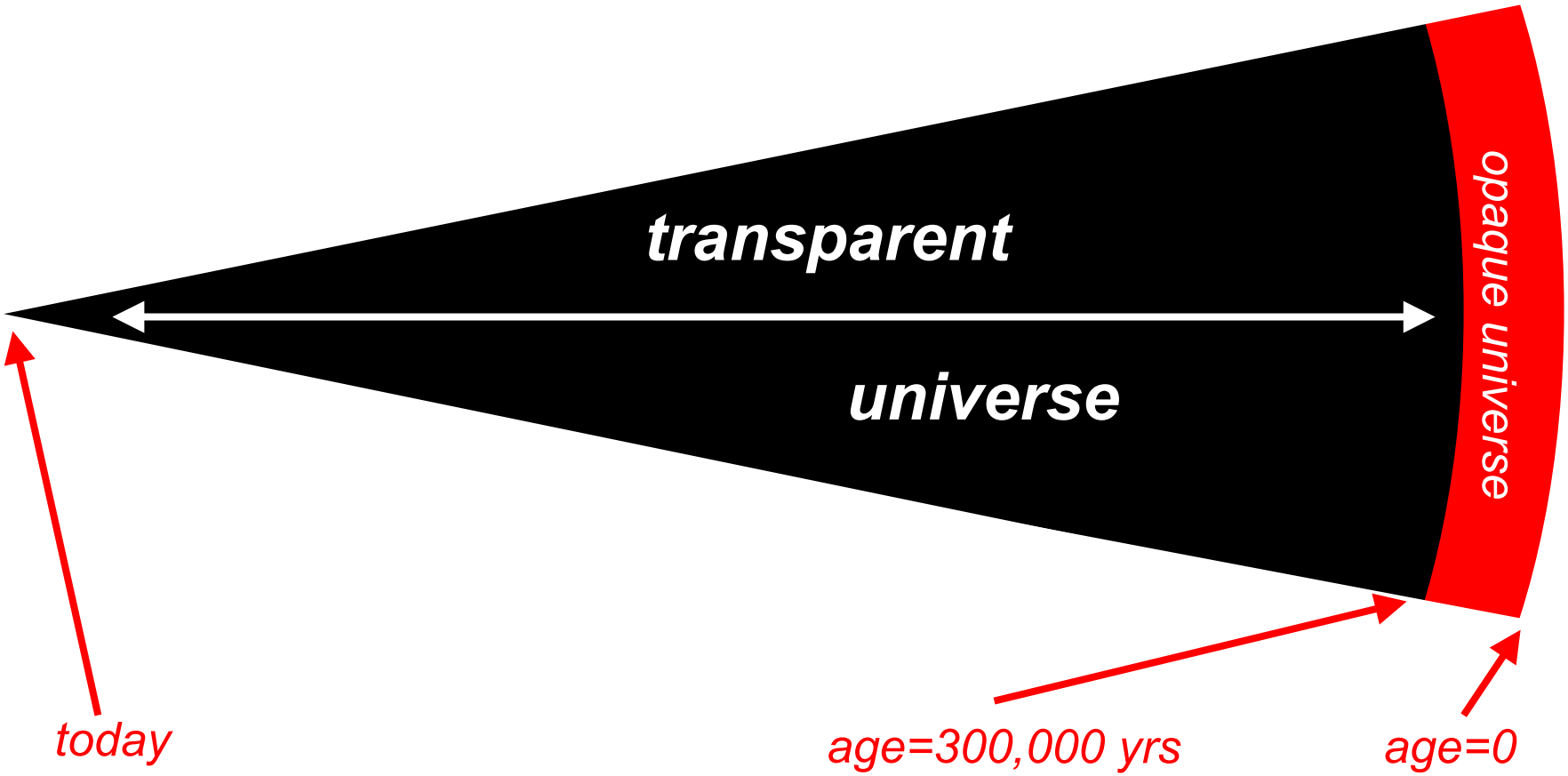
Cosmic background radiation

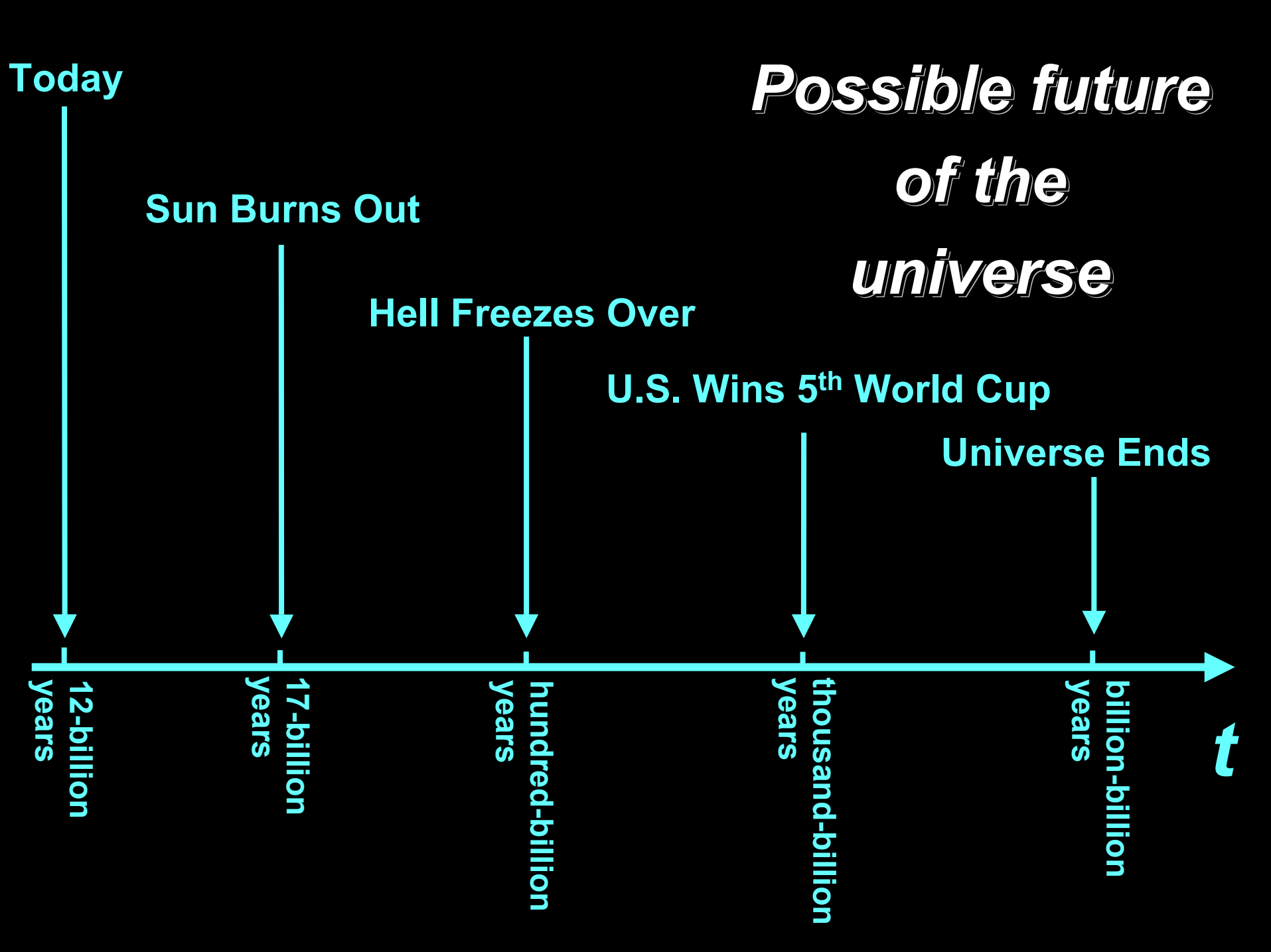


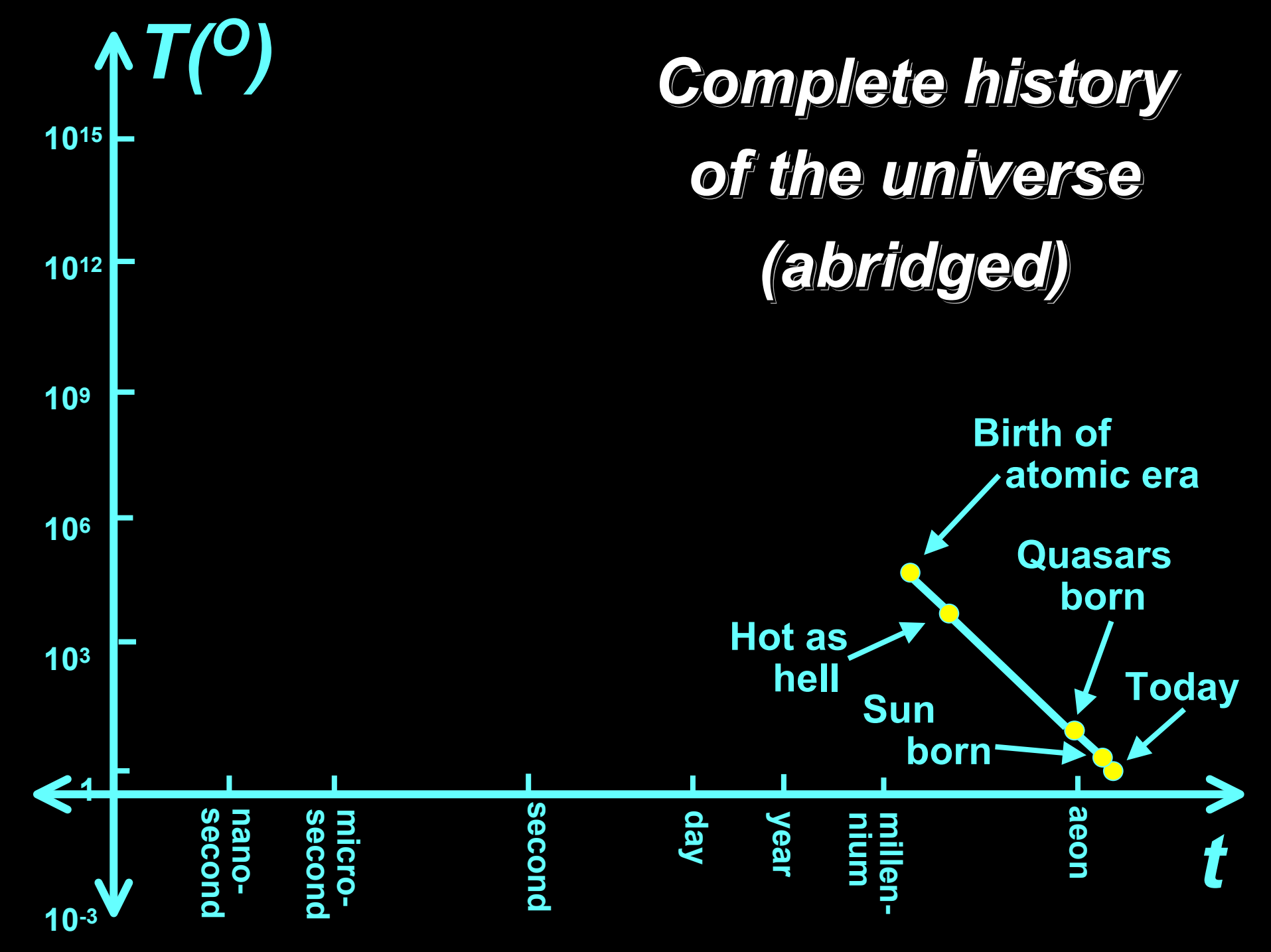
T = 3K = –270 C

Cosmic background radiation

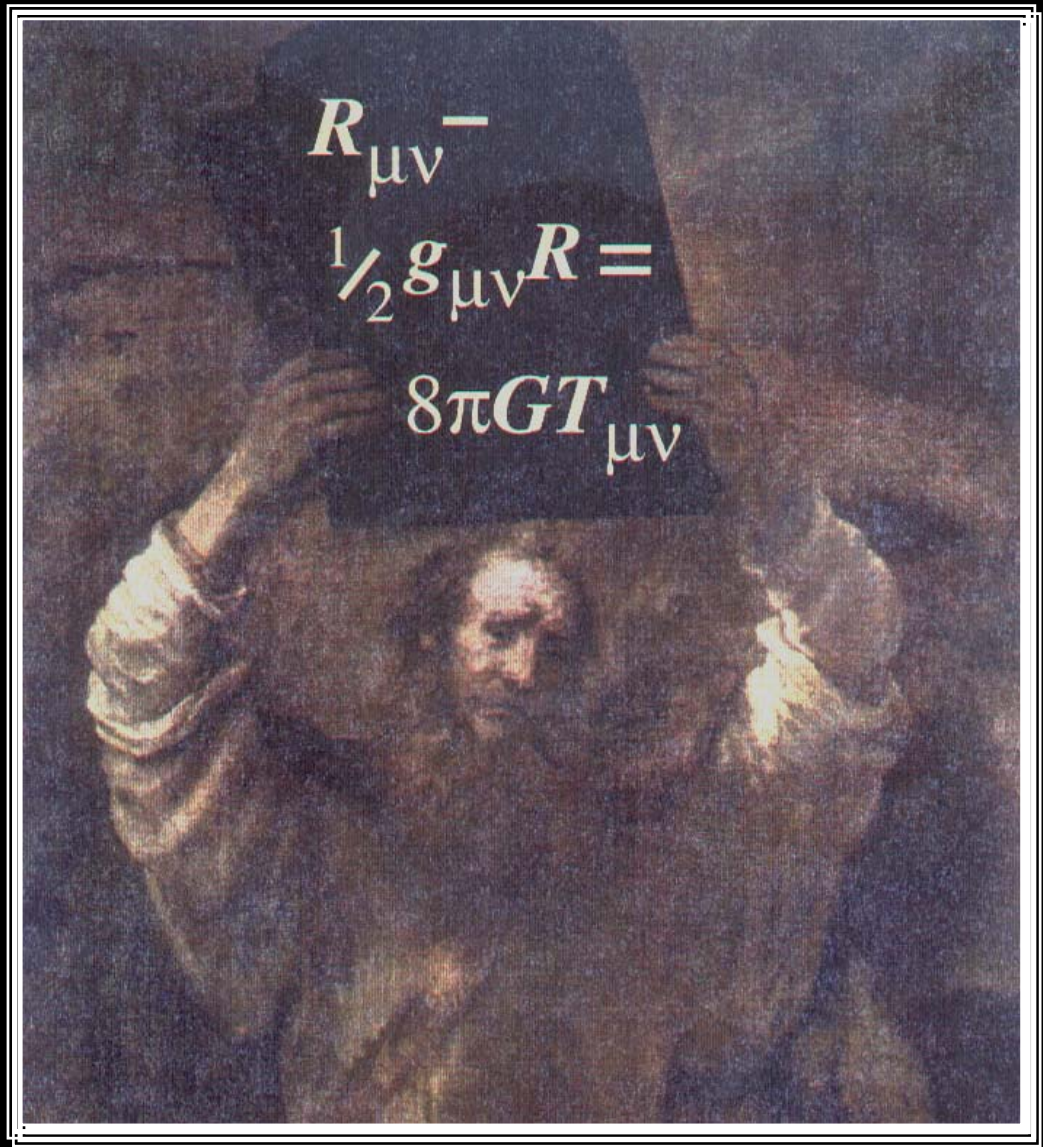
looking out in space is looking back in time




Possible future of the universe
Today
Sun Burns Out
Hell Freezes Over
U.S. Wins 5th World Cup
Universe Ends
12-billion years
17-billion years
hundred-billion years
thousand-billion years
billion-billion years
t


Complete history of the universe (abridged)
T(°)
10^15
10^12
10^9
10^6
10^3
1
10^-3
Birth of atomic era
Quasars born
Hot as hell
Today
Sun born
nano-second
micro-second
second
day
year
millen-nium
aeon
t

Modern laws of Genesis

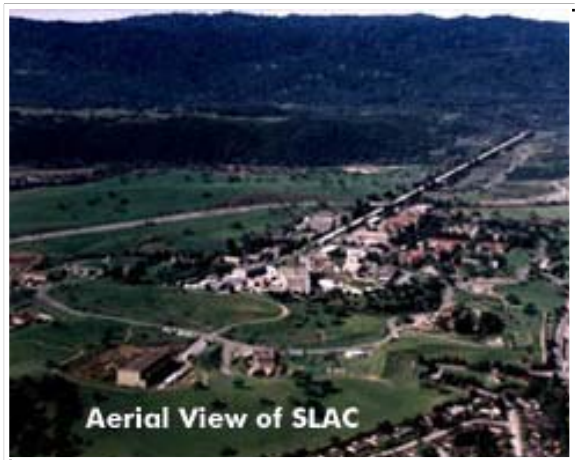


(10 nonlinear partial differential equations)

Fermilab – Batavia, USA

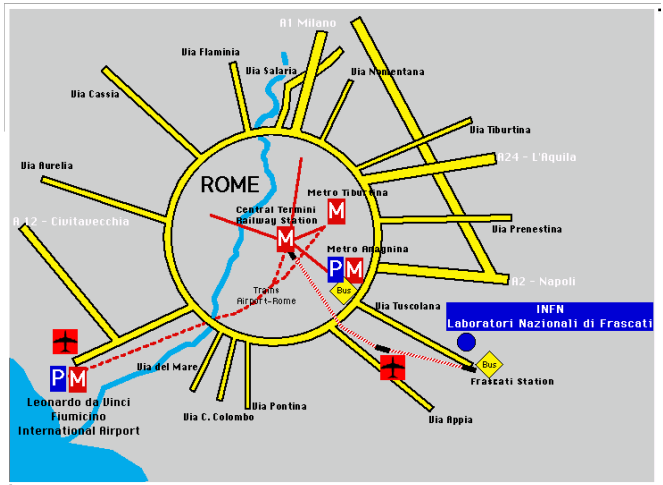
Particle Accelerator = Telescope = Time Machine

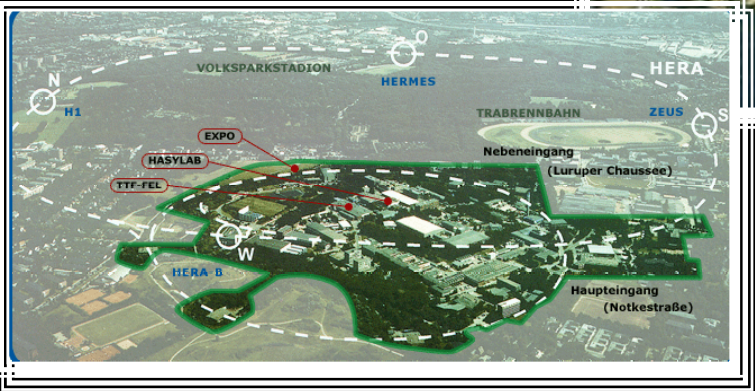
Stanford, USA



Geneva, Switzerland

Frascati, Italia

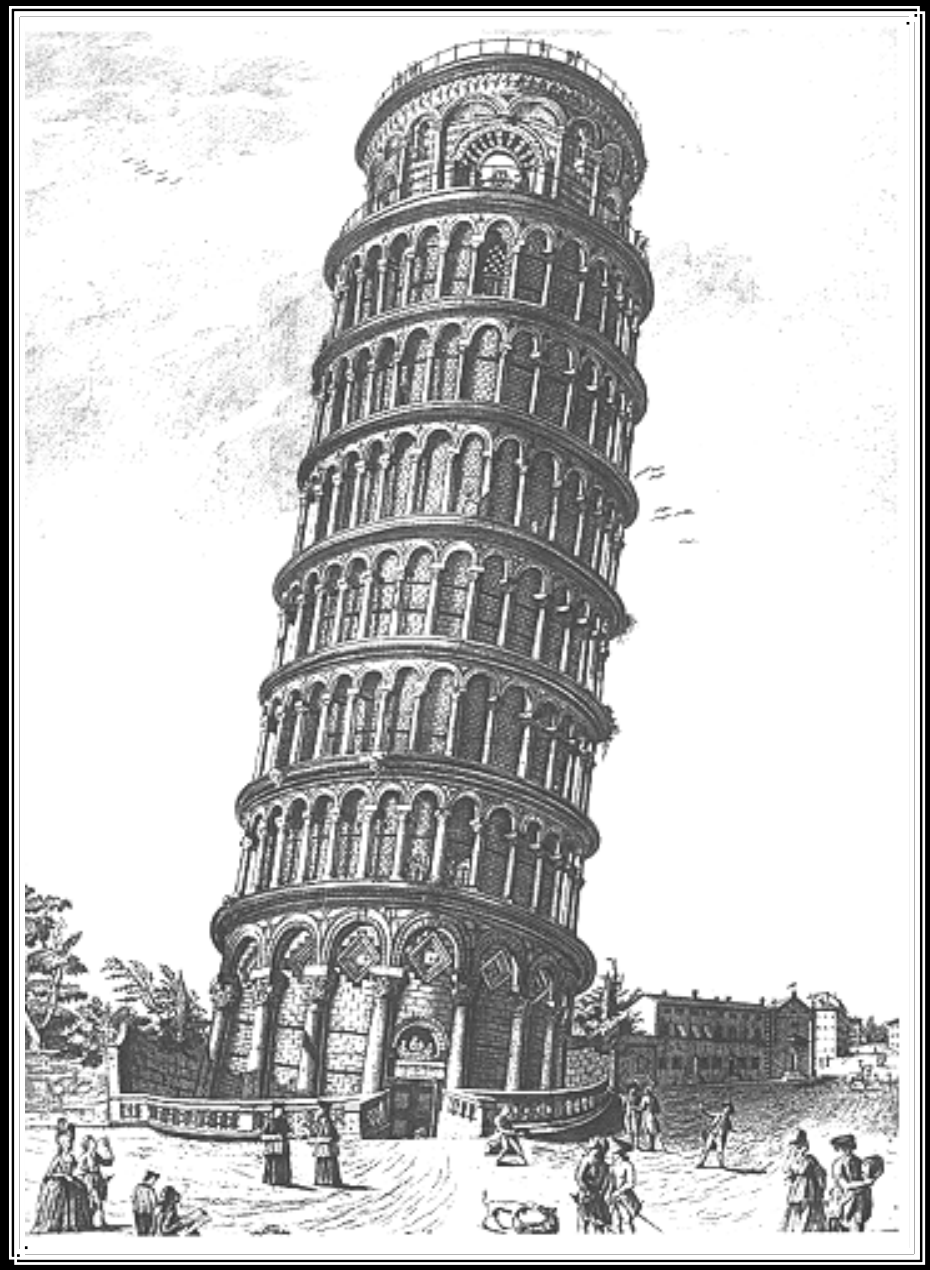




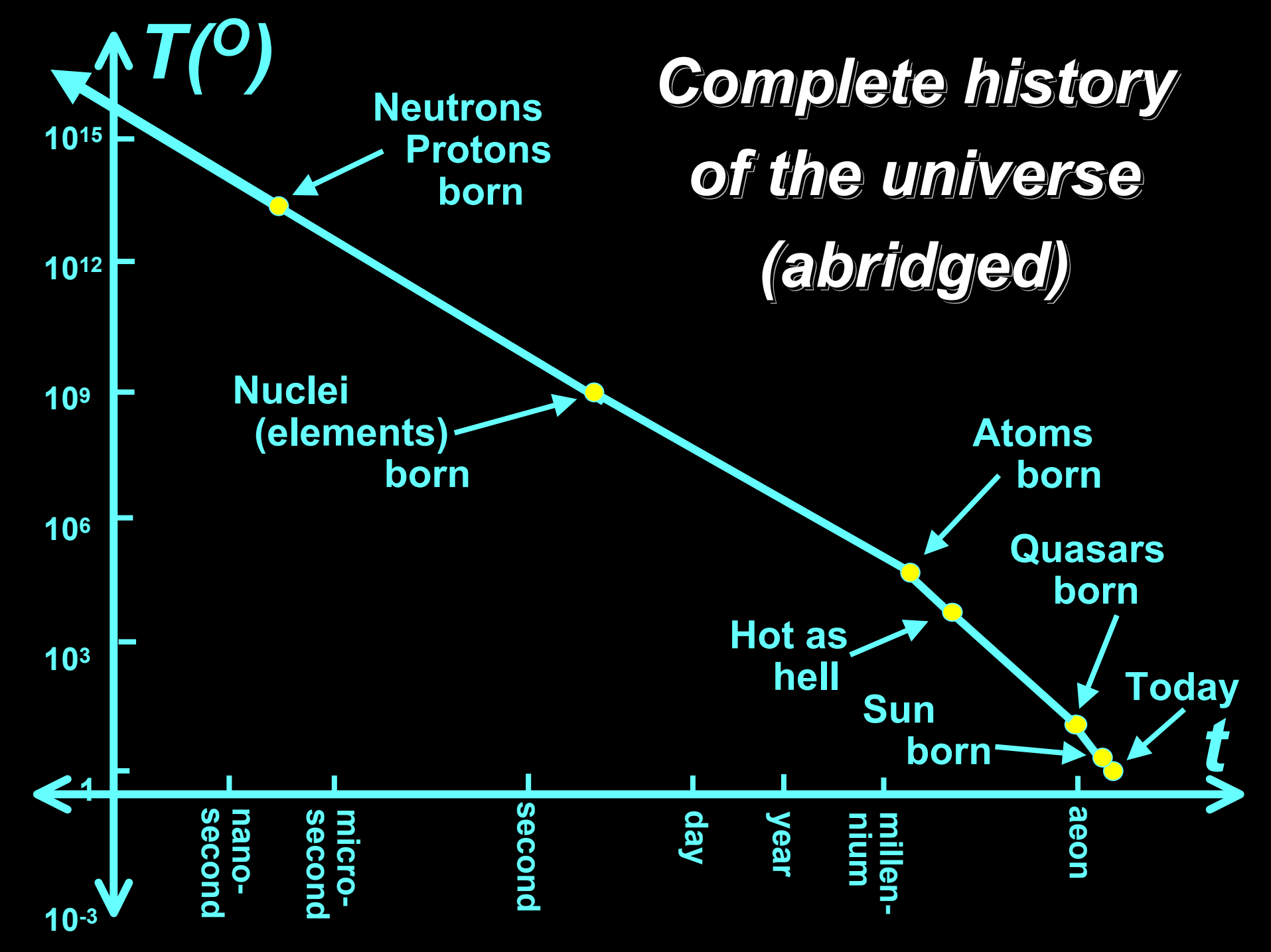
Hamburg, Germany

Tsukuba, Japan

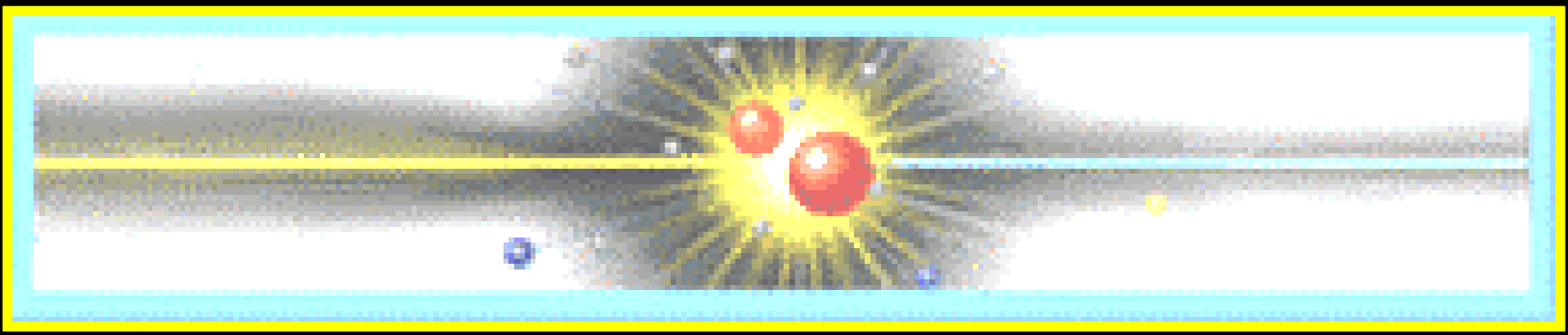
Pisan Accelerator Laboratory




Fermilabs
Primordial
SOUP


T(°)
Complete history of the universe (abridged)
Neutrons Protons born
Nuclei (elements) born
Atoms born
Quasars born
Hot as hell
Sun born
Today
t
10^15
10^12
10^9
10^6
10^3
1
10^-3
nano-second
micro-second
second
day
year
millen-nium
aeon

Primordial soup



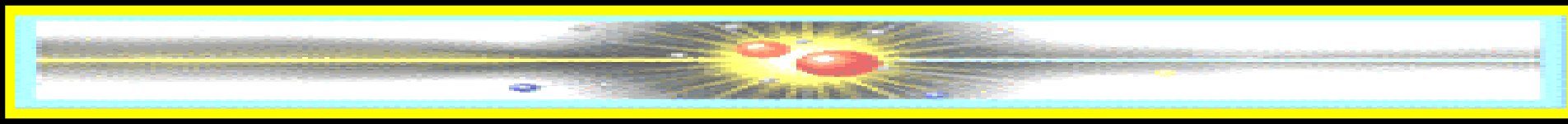
$3X10^{15}$ degrees

3,000,000,000,000,000°

$4X10^{-12}$ seconds

0.000 000 000 004 seconds

Primordial soup



Caution !!!

CONDENSED

50 Earth masses in matter
50 Earth masses in antimatter
\+ extra mountain of matter

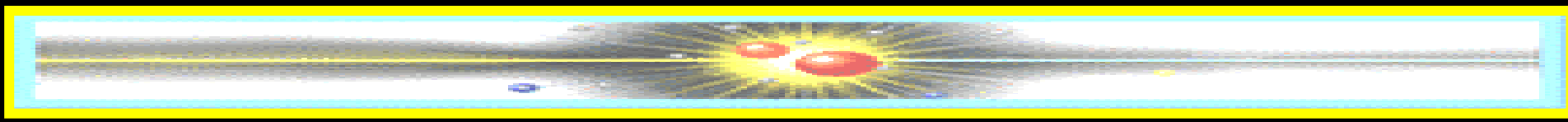
HOT

64 billion years of energy output of sun

CONTENTS

elementary particles and antiparticles

Primordial soup

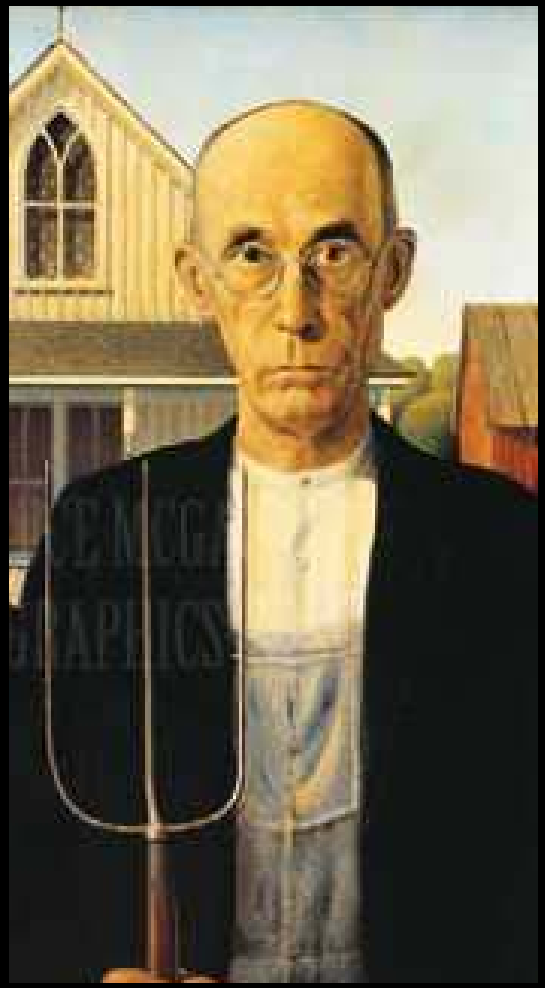


KNOWN INGREDIENTS:

56% QUARKS
16% GLUONS (STRONG FORCE)
9% ELECTRON-LIKE PARTICLES
9% W's AND Z's (WEAK FORCE)
5% NEUTRINOS
2% PHOTONS (ELECTROMAGNETIC FORCE)
2% GRAVITONS (GRAVITATIONAL FORCE ?)
1% HIGGS BOSONS (???)

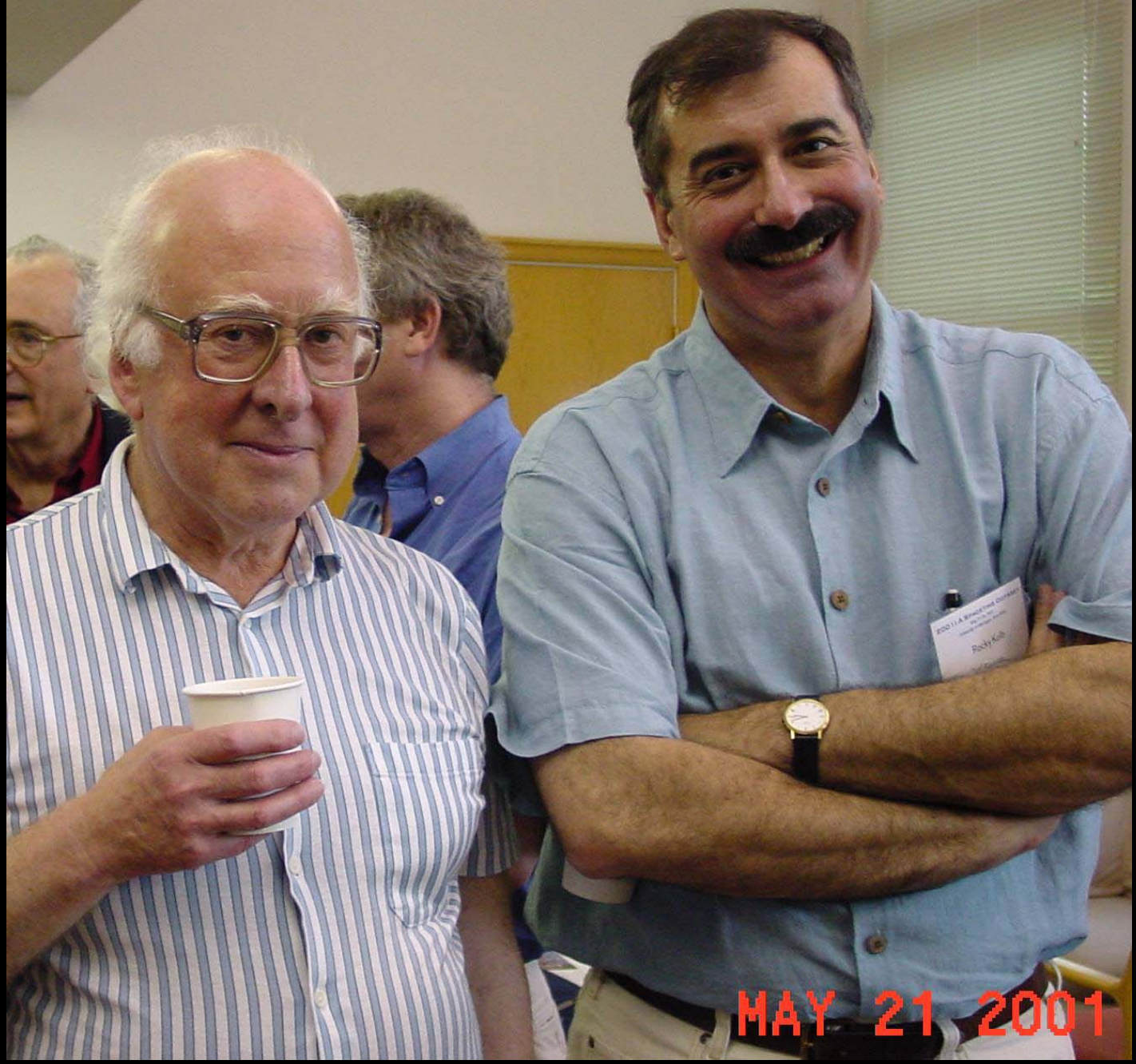
Will Higgs be found in

USA (Fermilab)? **or** **Europe (CERN)?**



Director

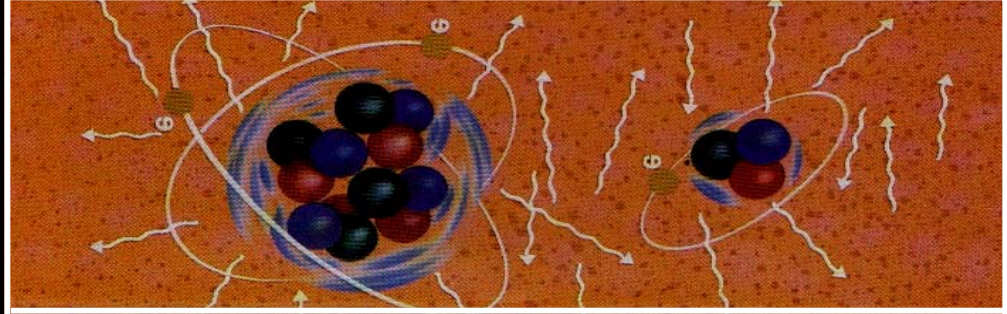
Luciano Maiani
Director General



Prof. Peter Higgs

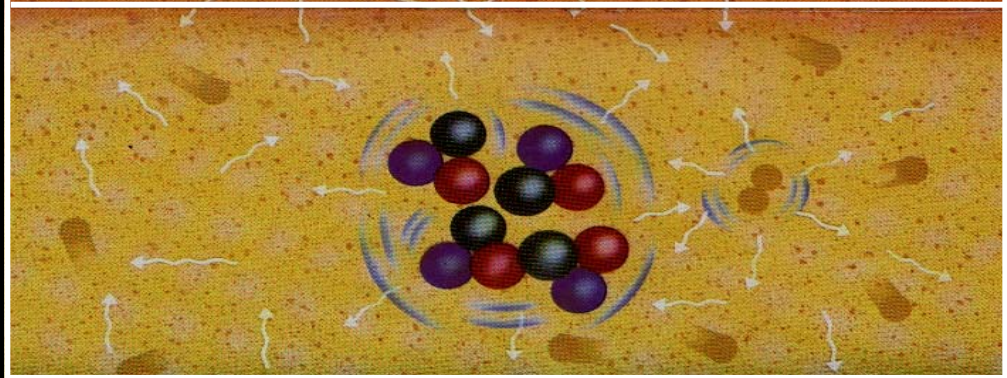
300,000 years

atoms form



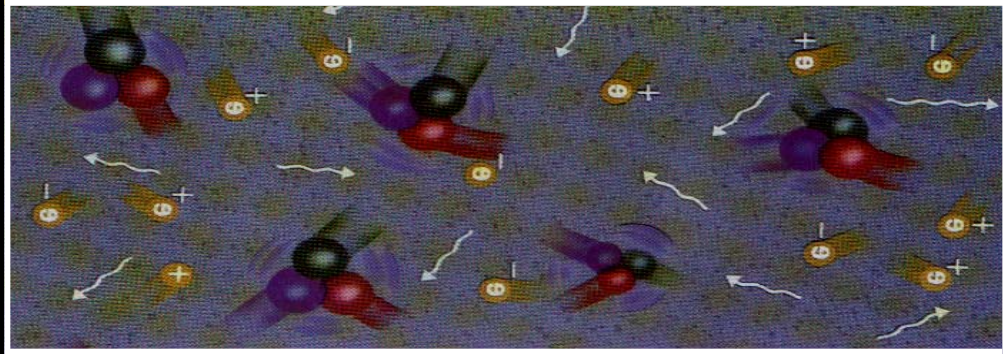
3 minutes

nuclei form



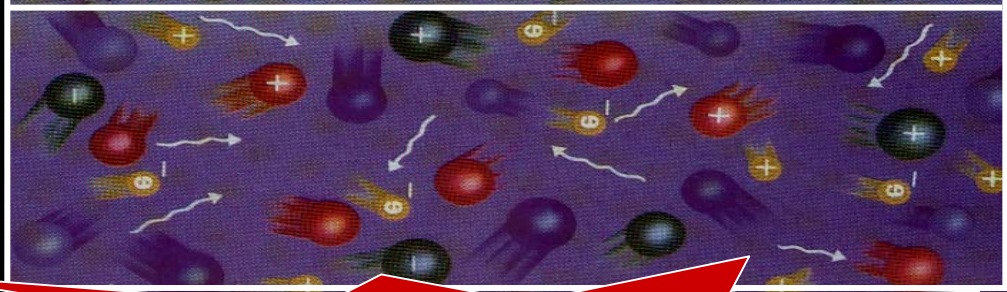
1-micro second

neutrons protons form



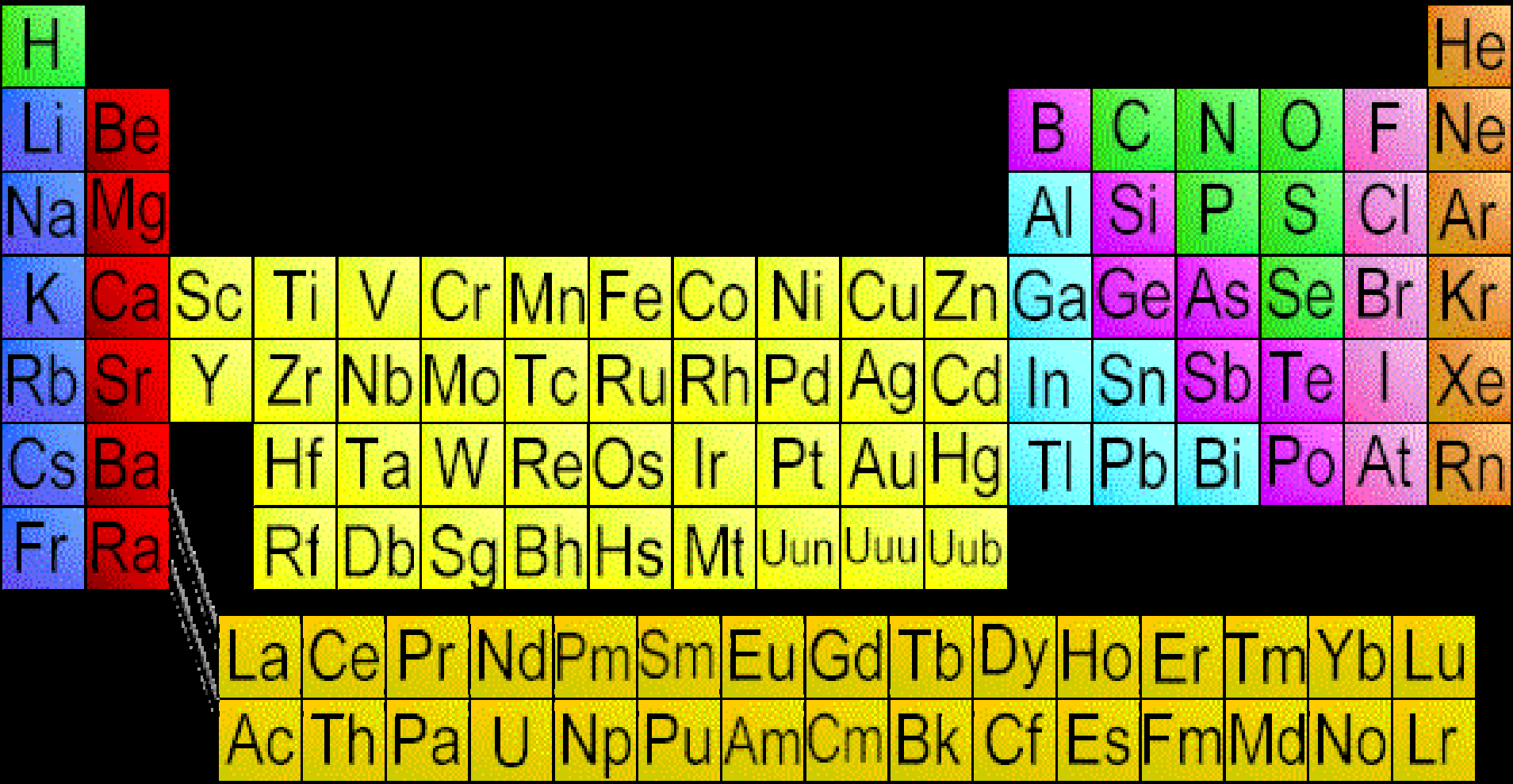
4-pico seconds

primordial soup

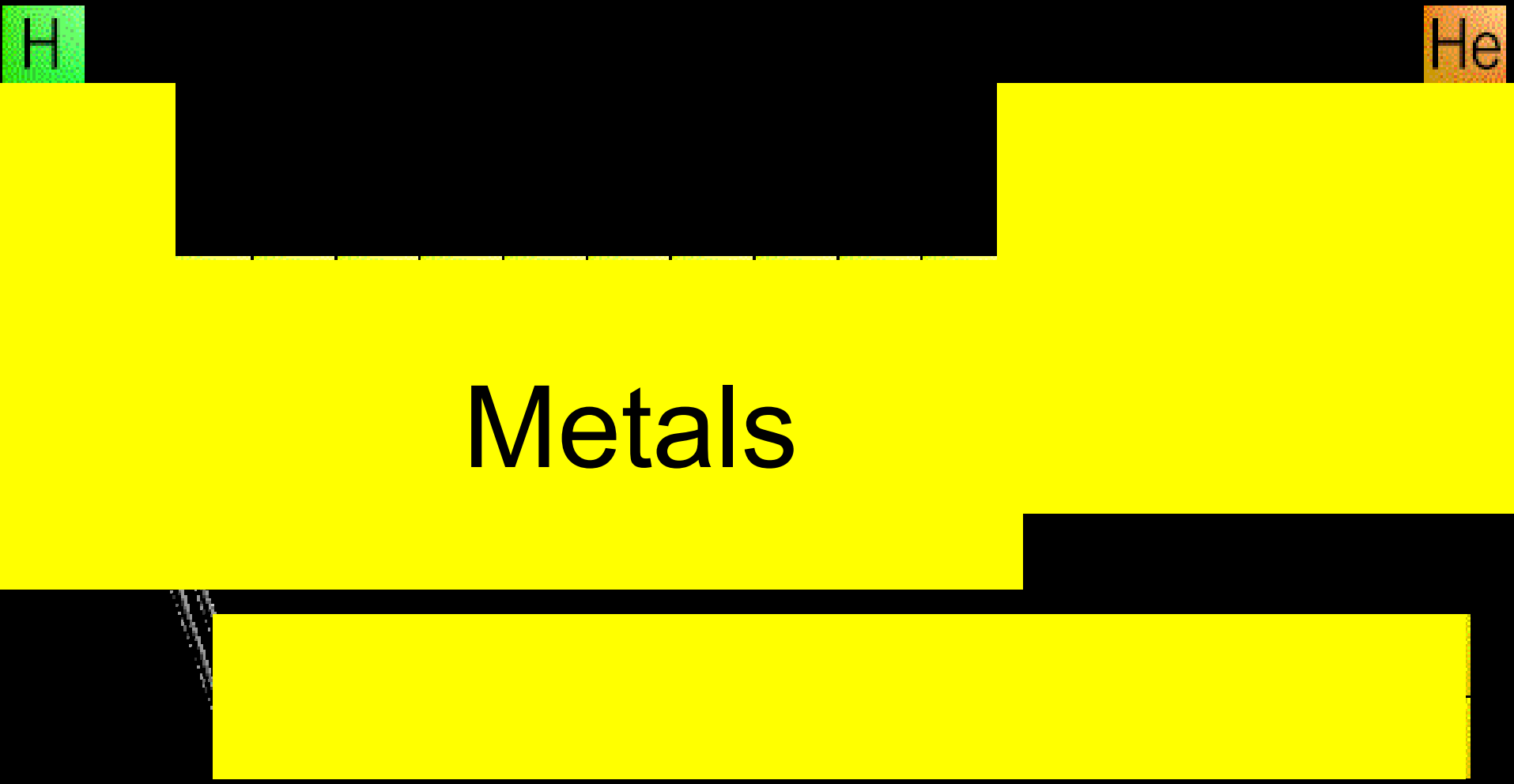


BANG!

Periodic table - chemist



Periodic table - cosmologist



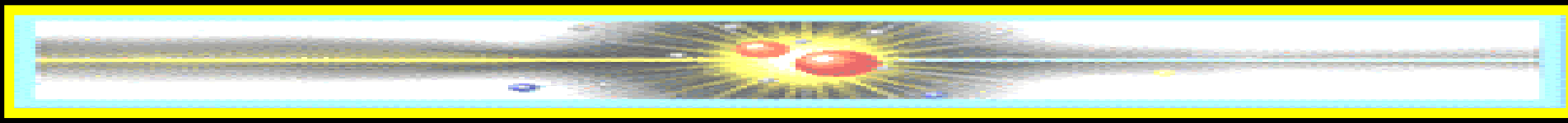
The Universe today:

73% Hydrogen (10^{-5} deuterium)
26% Helium (10^{-5} ^{3}HE)
1% Metals

The Universe 3 minutes AB:

76% Hydrogen (10^{-5} deuterium)
24% Helium (10^{-5} ^{3}HE)
10^{-8}% Lithium

Primordial soup



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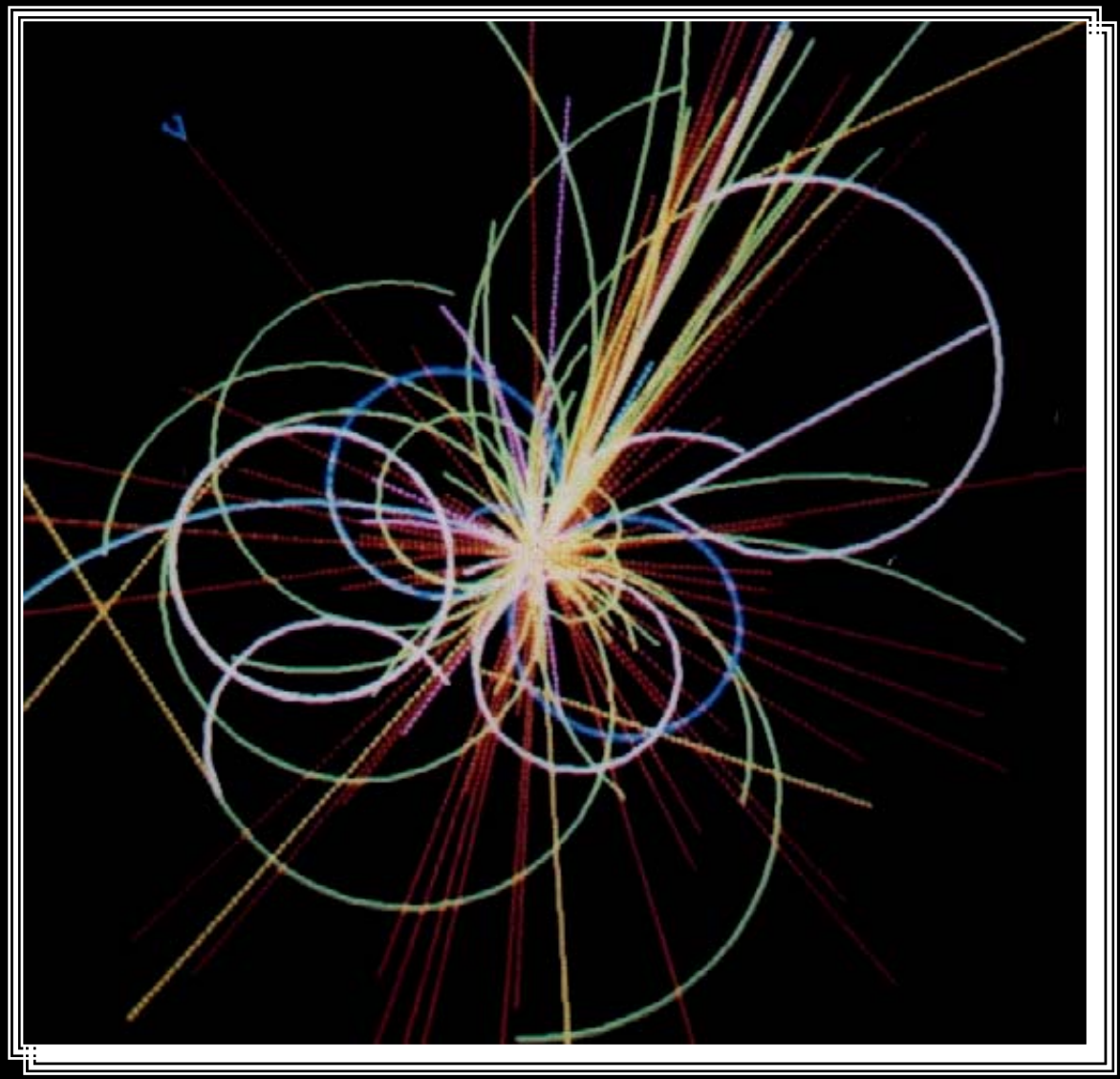
2% PHOTONS (ELECTROMAGNETIC FORCE)
2% GRAVITONS (GRAVITATIONAL FORCE)
1% HIGGS BOSONS (???)

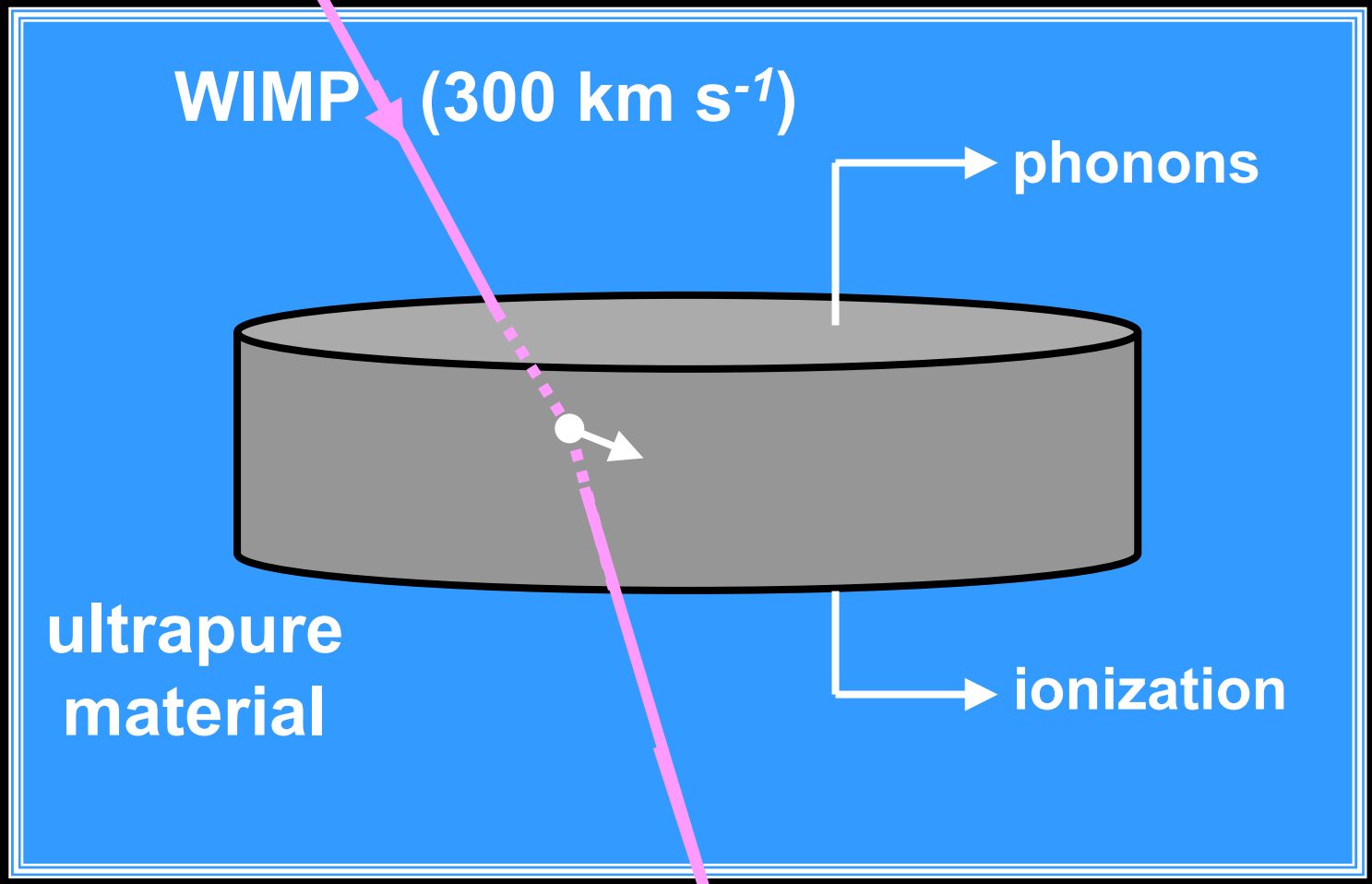
SECRET INGREDIENT:

DARK MATTER

Laboratory production of dark matter



Direct detection of dark matter

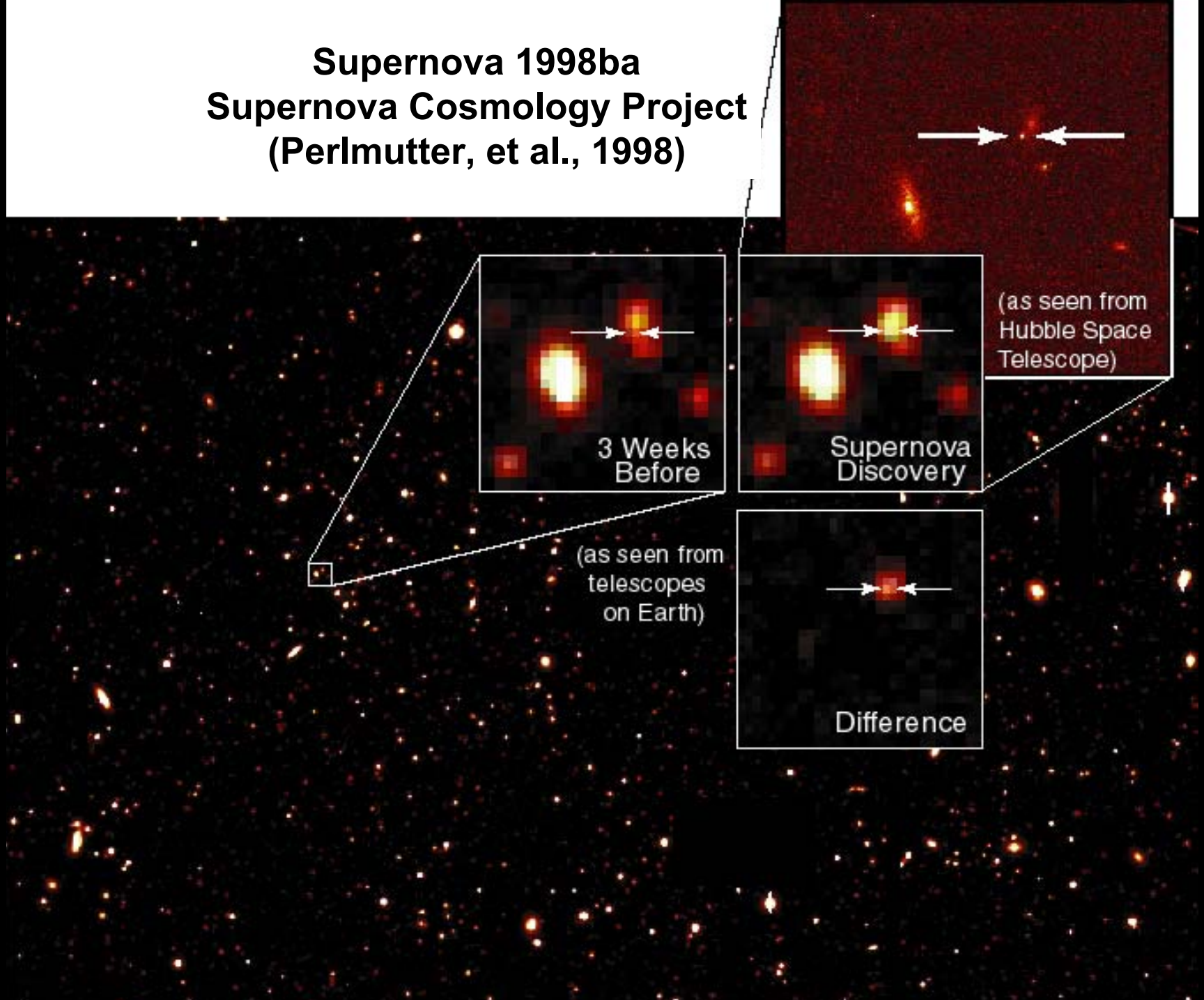


Most of the universe is dark !

- Modify Newton's laws
- Rocky planets
- Mass disadvantaged stars

  brown red white
- Black holes
- Fossil remnant of the big bang
- The weight of space

Supernova 1998ba
Supernova Cosmology Project
(Perlmutter, et al., 1998)



The accelerating universe?

- Supernovae dim-carried far away by the acceleration of the expansion of space
- Normal matter slows the expansion of the universe (deceleration). Gravity is attractive.
- Negative pressure would push apart space.
- "Vacuum energy" (the mass-energy density of space) is positive, but its pressure is *negative.*

Cosmological constant

1917: Einstein proposes cosmological constant

1929: Hubble discovers expansion of space

1934: Einstein calls it his “biggest blunder”

1998: Supernova evidence for acceleration

(was Einstein right the first time?)

Cosmo-illogical constant

Mass density of space:

$$\rho \approx 10^{-30}\ \mathrm{g\ cm^{-3}}$$

The unbearable lightness of nothing!

Think about nothing

NOTHING!!! (vacuum)

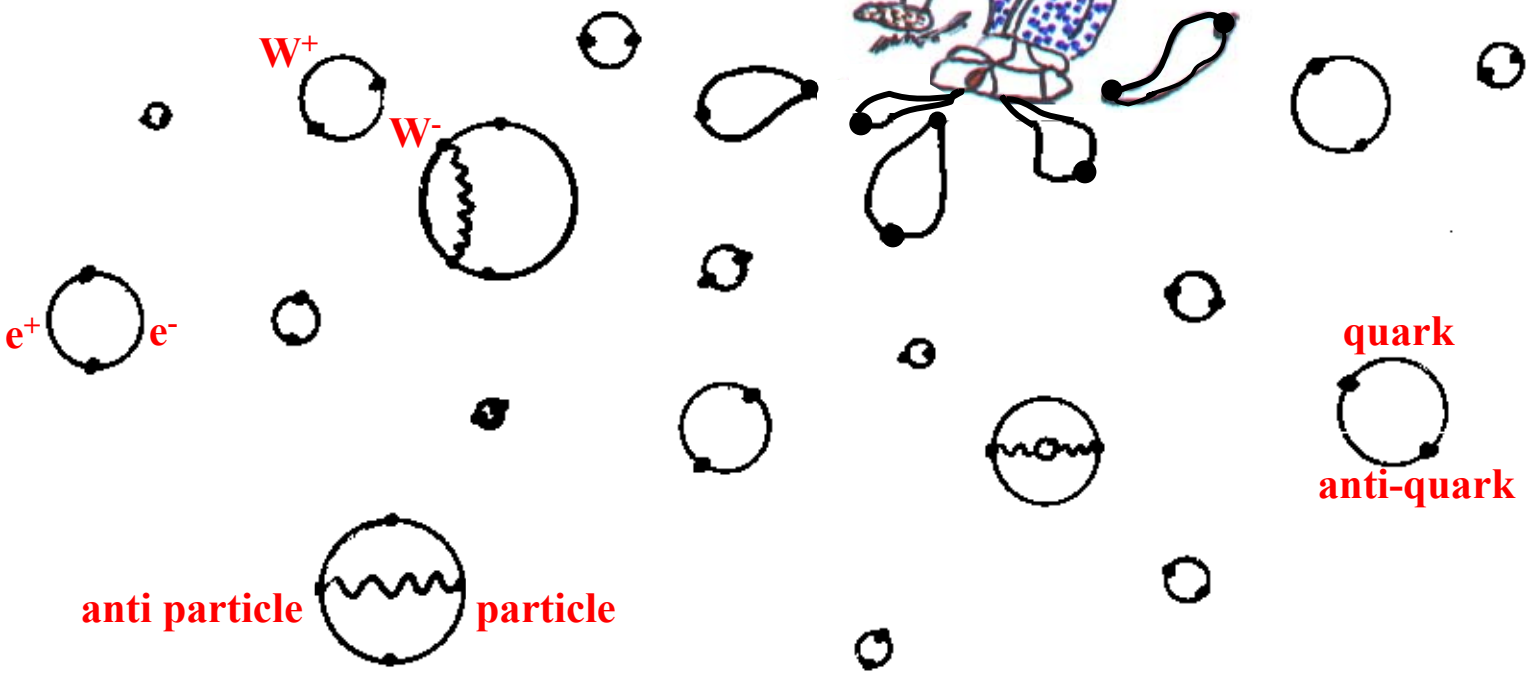
MUCH ADO ABOUT NOTHING:

NOTHING is something

NOTHING has energy

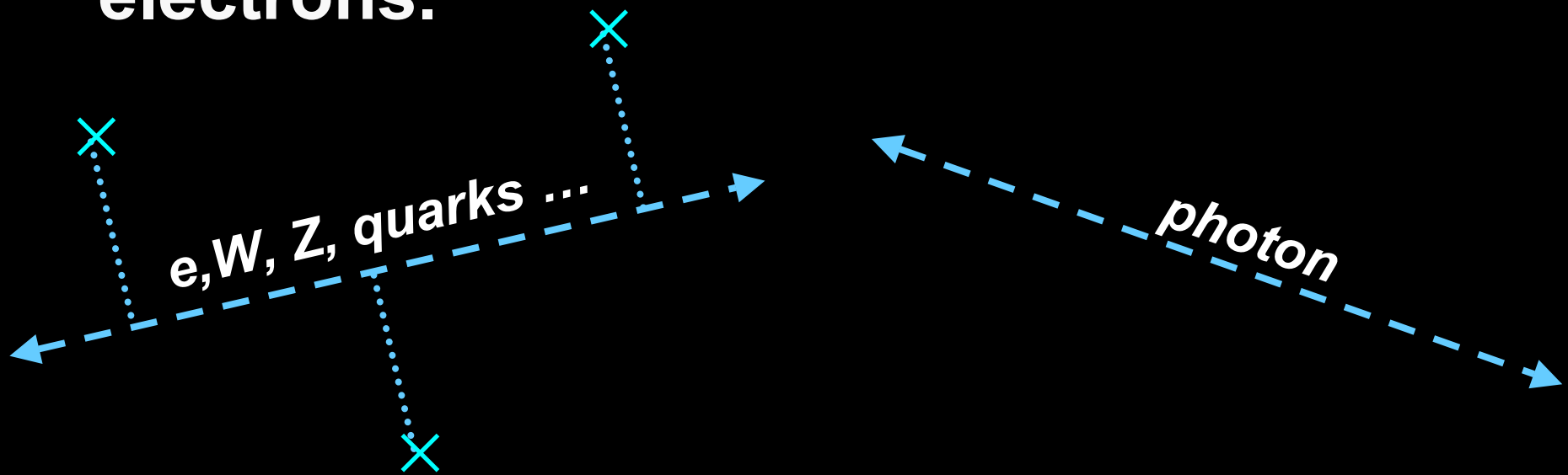
NOTHING matters!

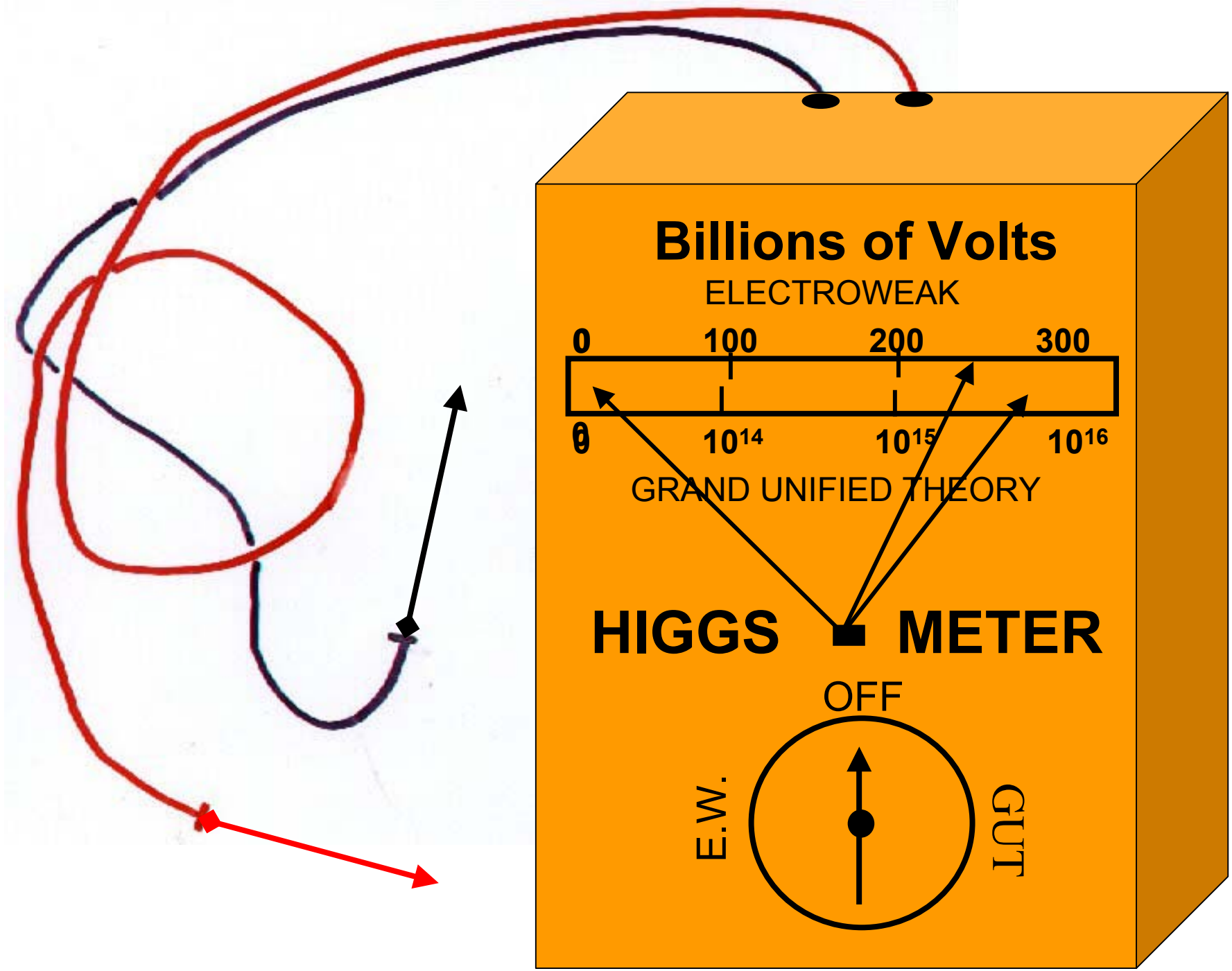
The Vacuum of Quantum Uncertainty



Nothing has energy: the Higgs potential

- The vacuum has a “Higgs potential”
- Interaction with the Higgs field potential gives mass to particles like quarks and electrons.



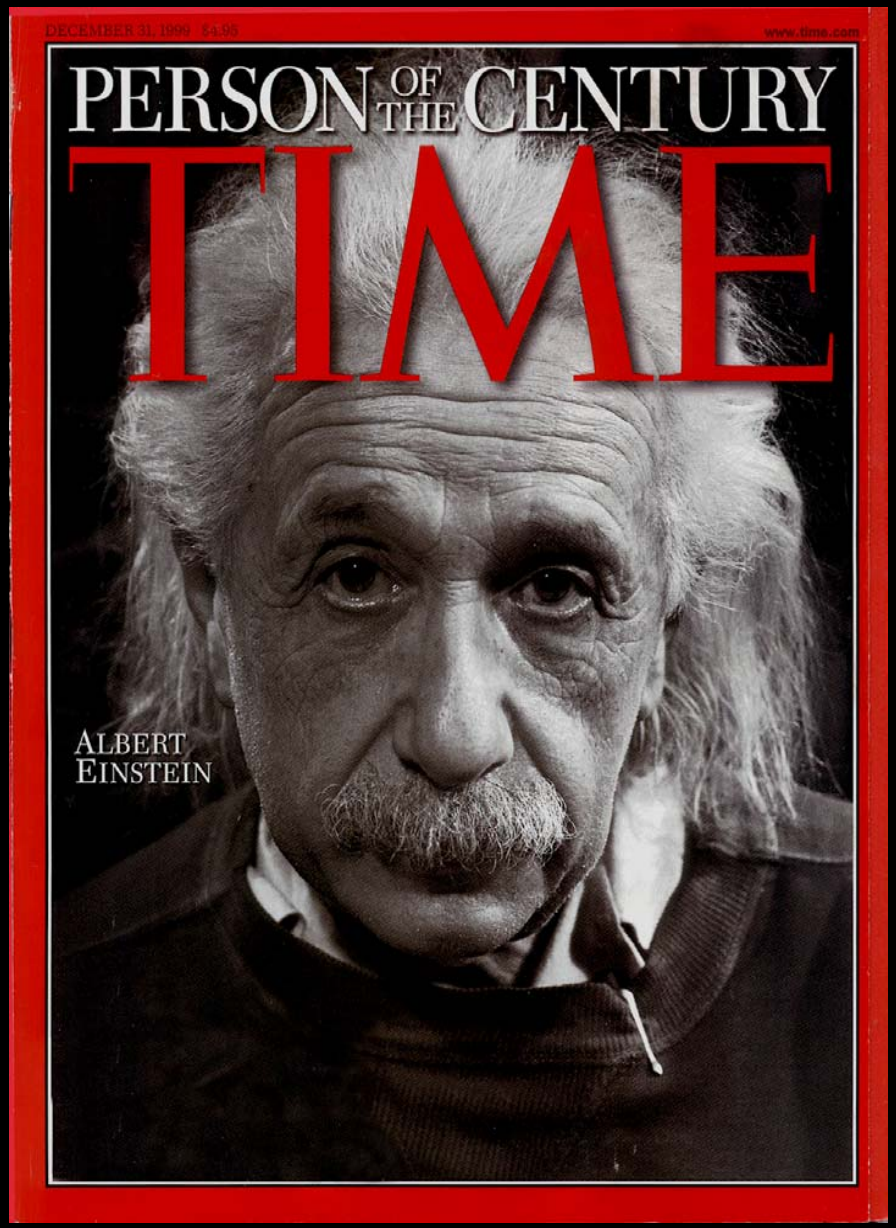

Billions of Volts
ELECTROWEAK
0
100
200
300
0
10^{14}
10^{15}
10^{16}
GRAND UNIFIED THEORY
HIGGS METER
OFF
E.W.
GUT

Every cubic inch of space is a

MIRACLE !

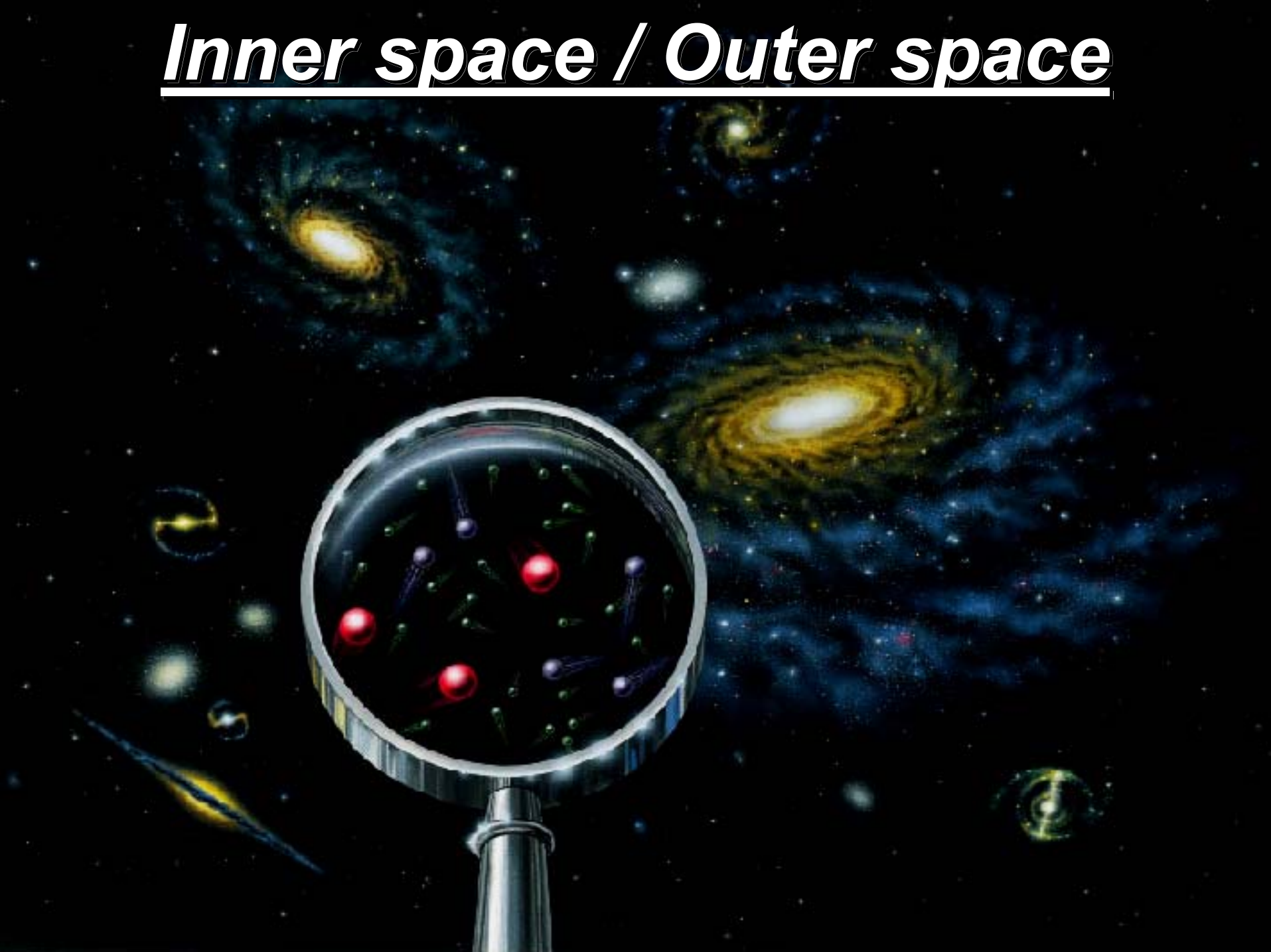
- Walt Whitman

- dark matter
- background radiation
- virtual particles
- Higgs vacuum


DECEMBER 31, 1999 $4.95
www.time.com
PERSON OF THE CENTURY
TIME
ALBERT EINSTEIN


DECEMBER 31, 2099 $24.95
www.time.com
PERSON OF THE NEXT CENTURY
TIME
?

Inner space / Outer space



The quantum & the cosmos

http://home.fnal.gov/~rocky/rio.pdf

Rocky Kolb
Fermilab,
Univ. of Chicago,
& CERN

27 July 2002
Rio de Janeiro